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The Journal of the INSTITUTION OF PRODUCTION ENGINEERS

Vol. XXII No. I

JANUARY, 1943

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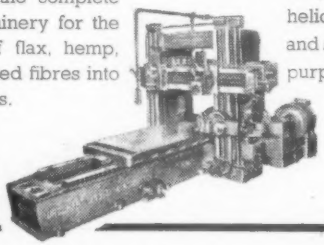

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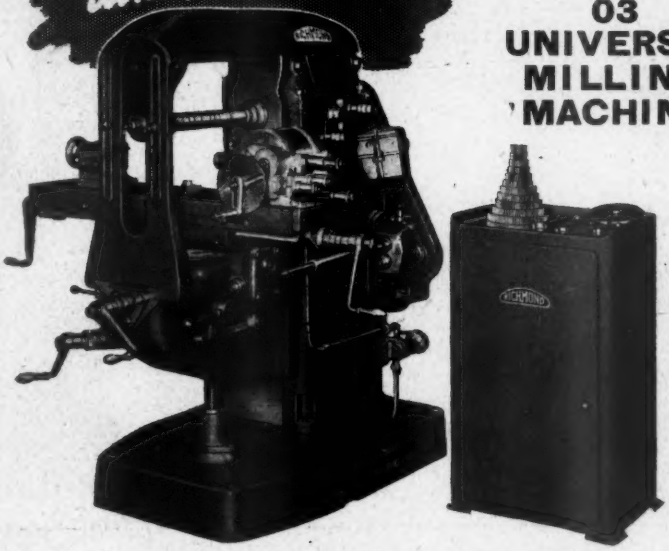

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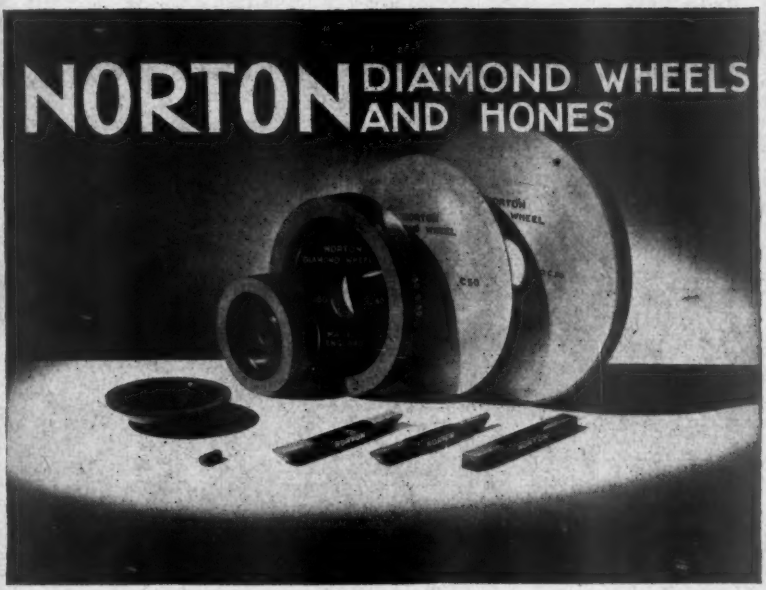

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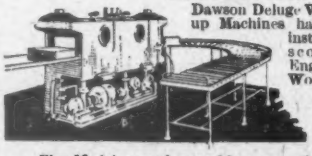

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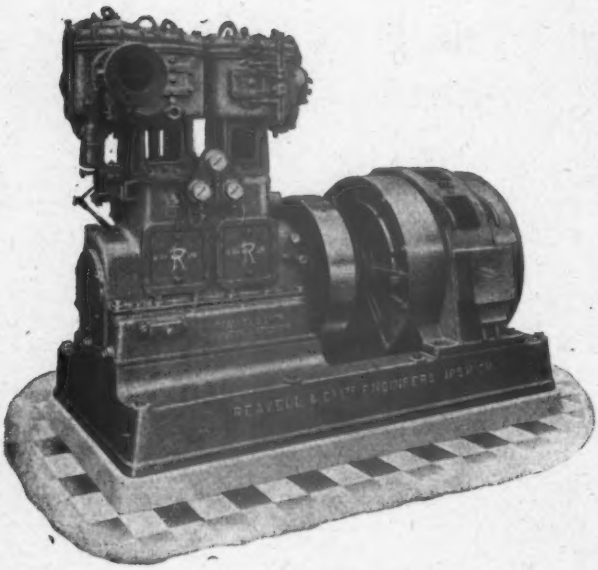

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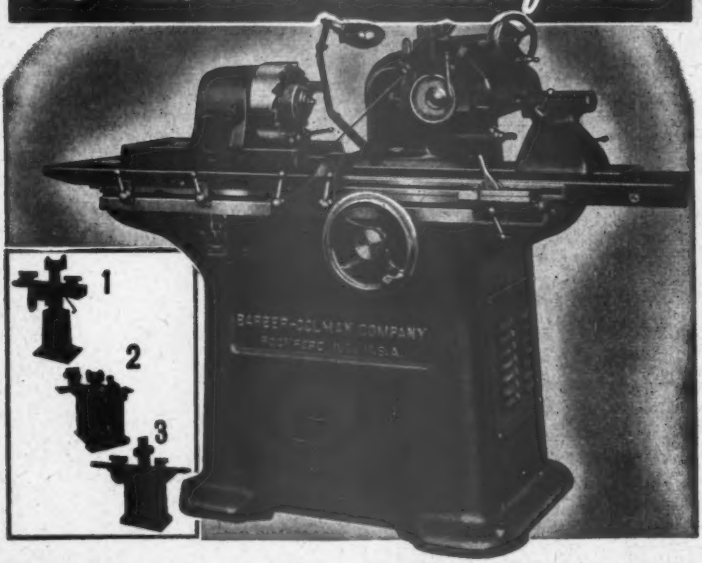

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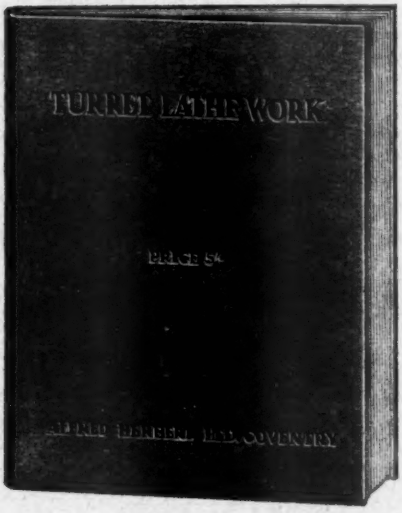

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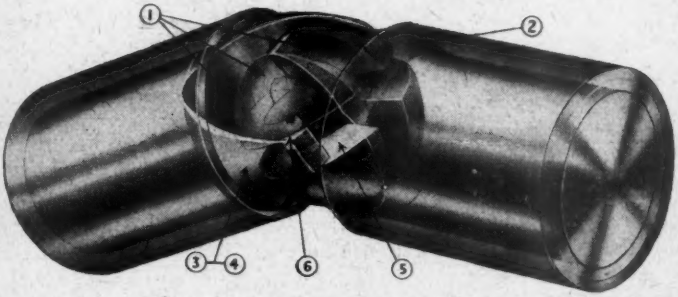

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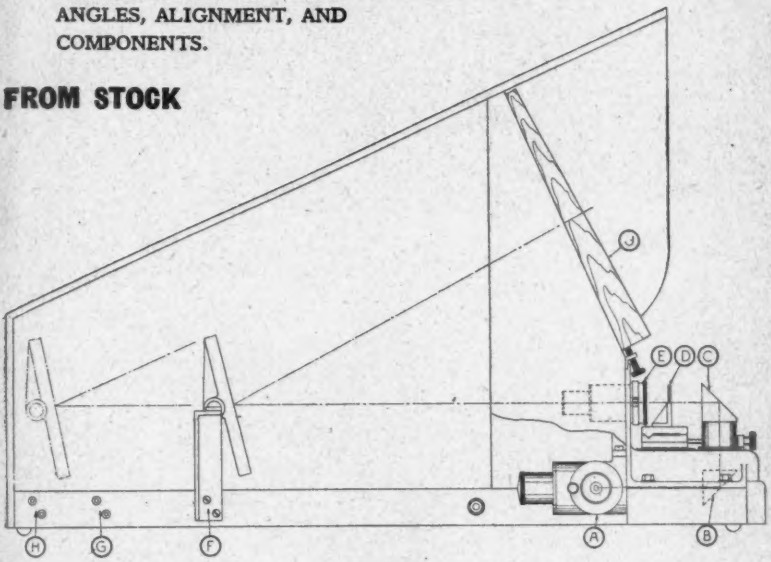

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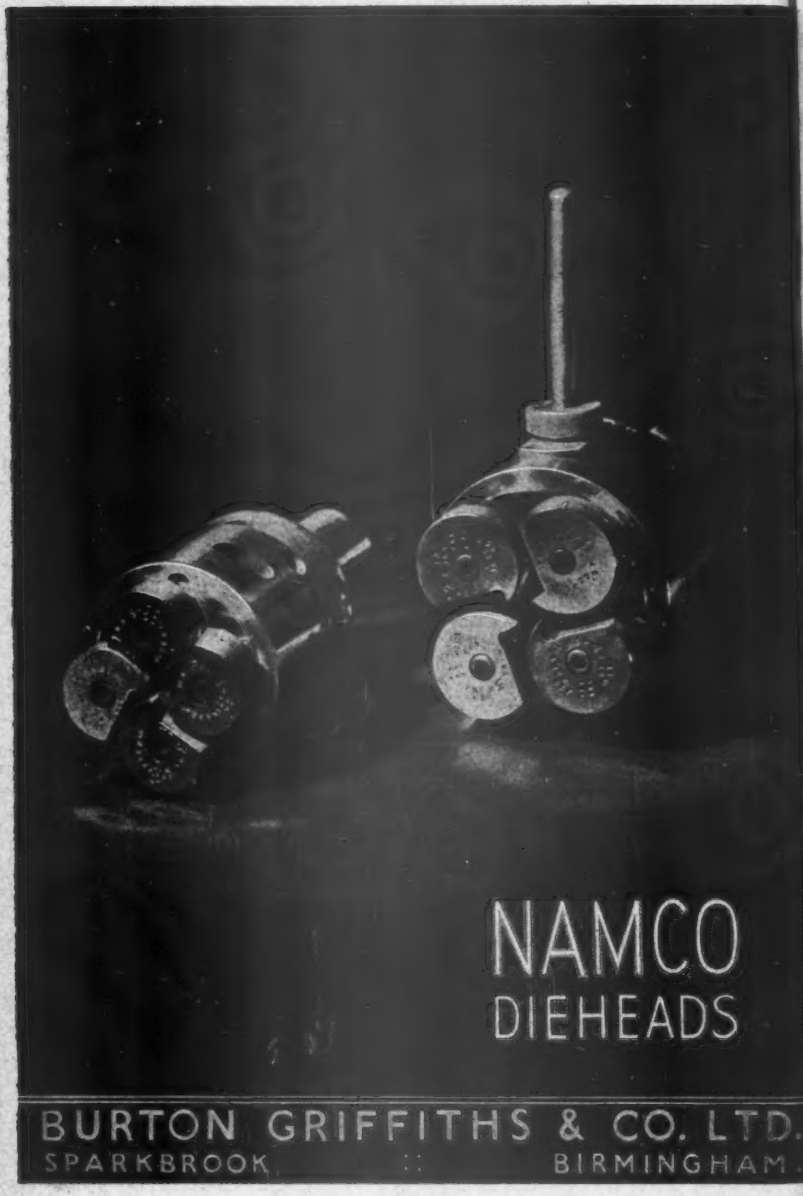
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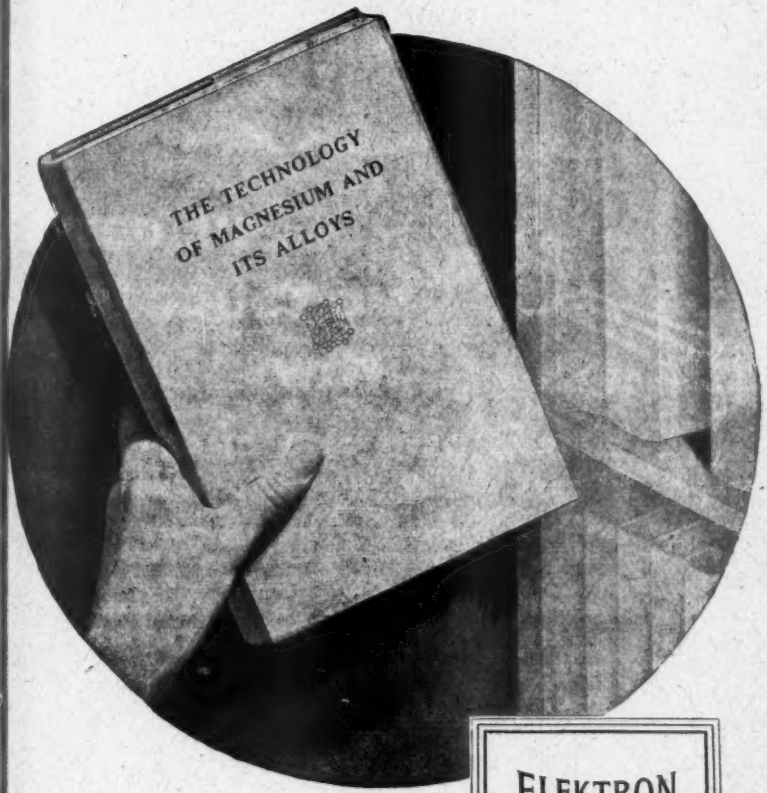

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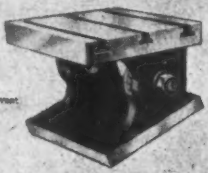

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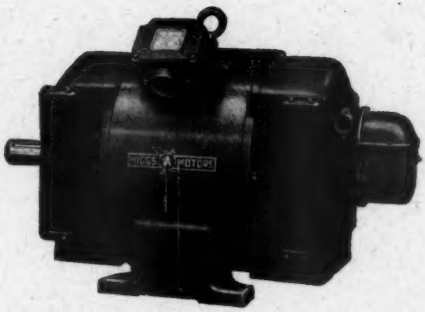

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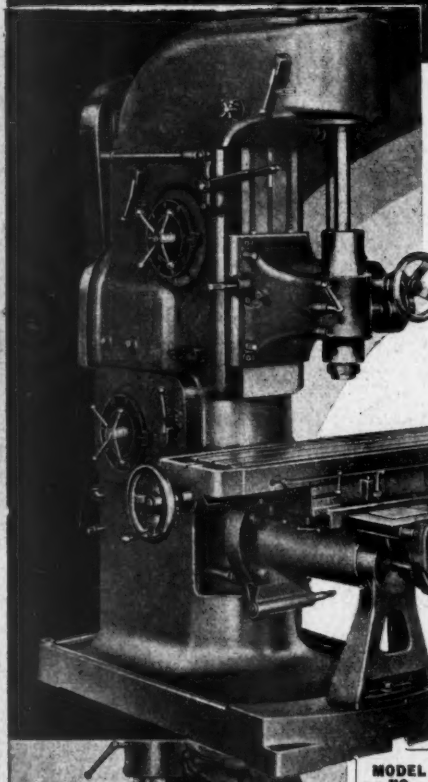

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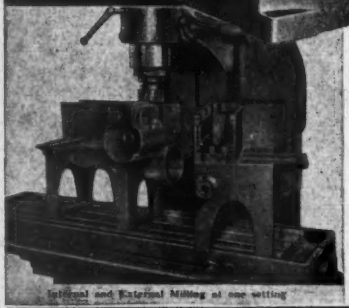

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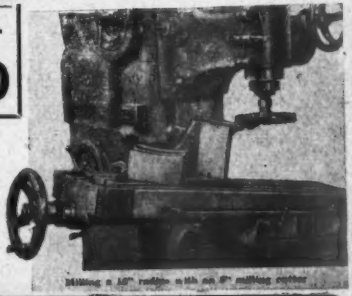

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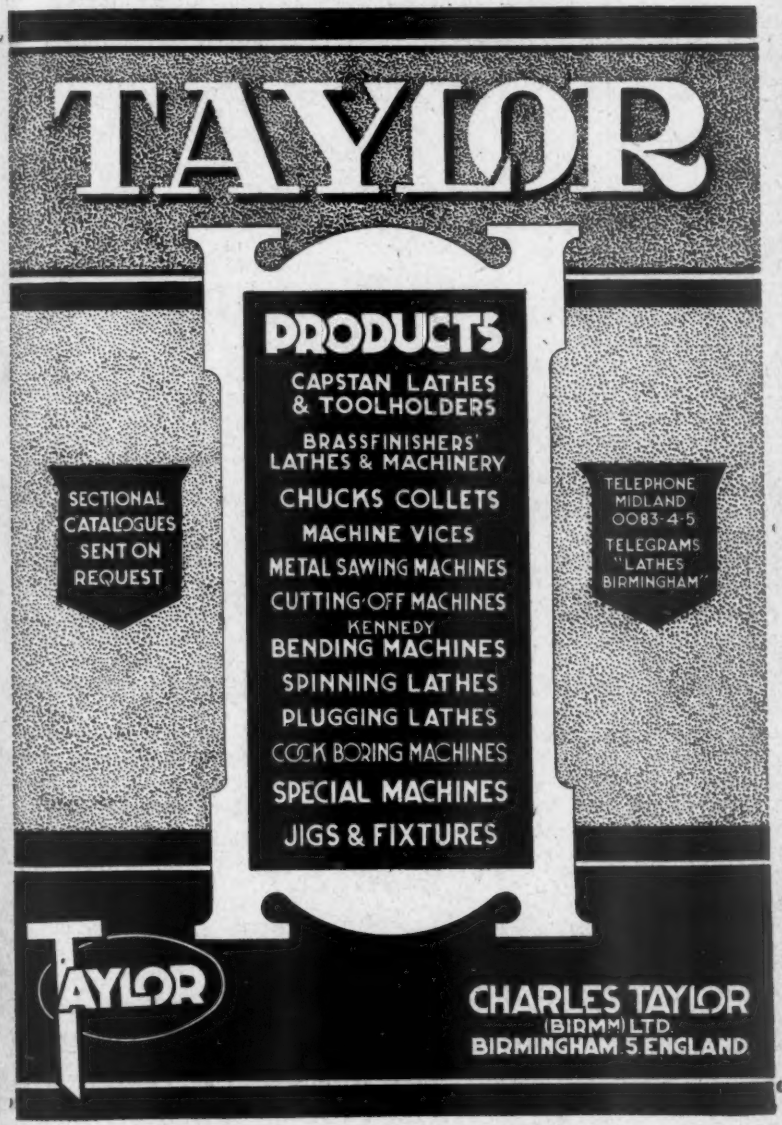
Pryor, Edward, & Son, Ltd.	xxiv A
Reavell & Co. Ltd.	viii B
Rotherham & Sons, Ltd.	xxiii A
Sanderson Bros. & Newbould Ltd.	x i A
Speed Tools, Ltd.	xx A
Stedall Machine Tool Co. Ltd.	xvi B
Taylor, Charles, Ltd.	xxix B
Taylor, Taylor & Hobson, Ltd.	xiv B
Timbrell & Wright Machine Tool Engineering Co. Ltd.	xxix A
Urquhart, Lindsay & Robertson (Orchar), Ltd.	ii B
Vaughan, Edgar & Co.	xxi A
Ward, H. W., & Co. Ltd.	v A
Ward, Thos. W., Ltd.	xxiv B
Wearden & Guylee, Ltd.	xxxi A
Wickman, A. C., Ltd.	ix A vii B
Wolverhampton Die Casting Co.	xxxi B

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "The Journal" should not be taken as an indication that they are necessarily available for export.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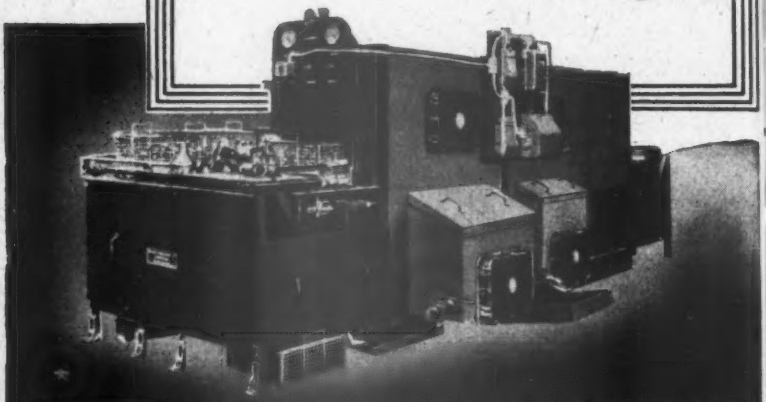

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INSTITUTION NOTES

January 1943

Fixtures.

January 29—Coventry Section. Lecture on "The Reclamation of Gauges and Scrap Material by Hard Chrome Deposition" by M. B. Booth, Esq.

January 29—North Eastern Section. Lecture on "Design of Drop Forgings" by A. Chilton, Esq., M.I.P.E.

January 31—Luton Section. Lecture on "Some Applications of Optics to Engineering" by Mark H. Taylor, Esq., M.I.P.E.

February 13—Yorkshire Section. Lecture on "Foremanship" by B. C. Jenkins, Esq., M.I.P.E.

February 24—Sheffield Section. Lecture on "Surface Treatment of Metals for the Prevention of Corrosion and Wear" by R. E. Shaw, Esq., B.Sc.

Obituary.

We deeply regret to announce the death of Mr. R. Hazleton, General Secretary to the Institution. This sad news reached us just as we were going to press and an obituary notice will appear in the next issue of the Journal. Mr. Hazleton underwent an operation on the 25th January and passed away early in the morning of the 26th January.

Personal.

1. New Year Honours List. Mr. John Curran, Affiliate Representative of Edward Curran & Co., Ltd. has received the honour of C.B.E.

2. Mr. P. B. Niekirk received the M.B.E. Mr. Niekirk is Works Manager of Messrs. John Fowler & Co., (Leeds) Ltd.

3. New Appointment. Mr. C. B. Northey (Member) has been appointed Assistant Controller, Inspection Operations, under the Controller of Inspection Administration, Ministry of Supply.

The following communication has been received from Field Marshal Sir John Dill, which is self-explanatory. Members wishing to subscribe to this fund are requested to state that they are members of this Institution :—

British Joint Staff Mission,
Offices of the Combined Chiefs of Staff,
Washington,
2nd November, 1942.

The Secretary,
The Institution of Production Engineers,
36, Portman Square,
London, W.1.

Dear Sir,

A fund has been registered under the War Charities Act, 1940, for educating at Cheltenham College the sons of engineers who lose their lives as a direct result of the war, whether they are in the services or are civilians. In the past similar steps have been taken to provide for the sons of doctors, clergy, and other professional classes, but so far as I know little has been done for the sons of engineers.

This is an engineers' war. All the fighting units depend for their efficiency on the engineer, both as part of their own strength and in the factories, supply services, transport, and mines. I can think of no better way of showing our gratitude to all engineers than by giving generously to this war charity. I am therefore writing to ask you to bring this fund to the notice of your readers. Donations, large or small, should be sent to me at the registered address of the fund, "The College, Cheltenham," cheques being made out to "The Cheltenham College Fund for Sons of Engineers."

Yours very truly,

J. E. Dill, F.M.

SPINDLE BEARINGS OF MACHINE TOOLS WITH HIGH SPEED

by G. Schlesinger, Hon.M.I.P.E.

THE increases of metal machining speeds in general, and of speed ranges (i.e. the ratio of max/min. speed) in particular, have set an immensely difficult problem for both machine tool designers and production engineers. In any machining process everything depends on the main spindle bearings—noiseless cutting action and freedom from vibration, both contribute to the production of first-class surfaces. If these main bearings are correctly designed and made the other rotating parts are of secondary importance provided, of course, that the teeth of all the driving gears have been cut with the necessary precision, the shafts are short and strong and the fits well selected.

We will therefore restrict this discussion to the main spindle bearings only.

The speed range is the starting point. We find with modern lathes of, say, 20 h.p. and 25 in. swing, a range of 15 steps from $\frac{12}{1200} = \frac{1}{100}$. With a front journal diameter of 5½ in. the maximum circumferential speed will be $v = \frac{\pi \times 5.5 \times 1200}{12 \times 60} = 29$ ft./sec. which is very high.

According to the catalogues of well known firms good radial drilling machines have speed ranges such as

$$\frac{12}{850} = \frac{1}{72}, \quad \frac{19}{1320} = \frac{1}{70}, \quad \frac{38}{2150} = \frac{1}{56}, \text{ etc.}$$

The safe running of a bearing is influenced not only by a wide range but by the actual number of revolutions. We must take into consideration the fact that the same bearing must be suitable, for say 38 and also for 2150 r.p.m. A range of $\frac{12}{1060} = \frac{1}{90}$ is less dangerous than one of $\frac{38}{2150} = \frac{1}{56}$ because the maximum speed is only half as much. In the expression $p \times v$, which indicates the bearing's capacity, p is the unit pressure in lb/sq. in. and v the circumferential speed in ft. per second. An average value is $p \times v = 200$ with $p \times v$ max. = 275 lb./sq. in. per second. If the number of

revolutions is high the pressure on the bearings of a machine tool is small because the power equation N = c.F.v. (material coefficient × force × speed) is fixed by the capacity of the existing drive. In the two formulæ the minimum pressures (p) or forces (F) are connected with the maximum speeds (v). A main spindle will work much more safely at 12 (or 38) r.p.m. and maximum pressure (heavy roughing cut) than with 1200 (or 2150) r.p.m. and minimum pressure (finishing cut). However, the oil clearance, the means of lubrication and the smoothness of the surfaces chiefly determine the conditions under which the spindle will work. It must be realised that the same bearing with the same lubrication and the same tolerance must work at one moment at 38 and soon after at 2150 revolutions, e.g. a radial drill using a big tap in steel and a small drill in brass. These are extraordinary and very difficult conditions which do not exist in any other types of machines whether electrical, hydraulic or mechanical.

The efficiency of bearings is based on the exclusive use of fluid friction. There must always be a thin but perfectly continuous layer of lubrication, which separates both sliding surfaces permanently and prevents direct contact which gives rise to wear. The main tasks of lubrication* are :—

(1) Elimination of wear.
(2) Diminution of friction.
(3) Decrease of oil consumption.
(4) Increase of load carrying capacity.

Perfect lubrication is only attainable by fluid friction, which follows the laws of the friction of fluids. Well designed and correctly lubricated cylindrical bearings show no wear at low working temperatures, less than 50° C.

Two main demands must be achieved :—

(1) The lubricating layer between the sliding surfaces must be of " wedge " shape. The lubricant should be carried by the movement of the journal from the wide back to the knife edge of the wedge.

(2) The peripheral speed must be so high that the oil pressure, created by the rotation of the journal, suffices to lift the rotating cylinder from the shell.

The correct clearance between journal and bearing is the prime factor on which the maintenance of a satisfactory oil wedge depends.

The peripheral speed of the rotating journal must be high enough to create the necessary oil pressure. The greater the speed the thicker will be the oil film at its thinnest point.

---

* Hydrodynamic Theory of Lubrication : Experiments by Beauchamp-Tower, Interpreted 1886 by O. Reynolds; Mathematical Data 1904 by A. Sommerfeld; 1931 Schmiertechnik by Falz.

The oil film shall get its maximum thickness when the journal realises its perfect concentric position to the bearing. Theoretically this would be the case with infinitely high speed. Then the oil film would be uniformly thick all around the journal; it would have a thickness of half the clearance (Fig. 1). The two extreme positions are :—

(1) Rest : minimum thickness of oil film = 0 ; pivot touches bearing.

(2) Infinitely quick rotation : maximum film thickness (b) = half of clearance.

Indispensable conditions for the correct function of the lubrication are (1) that there is no detrimental interruption of the wedge effect by arranging the oil grooves in the wrong place. *It is better to avoid oil grooves completely.* (2) the viscosity of the oil must be

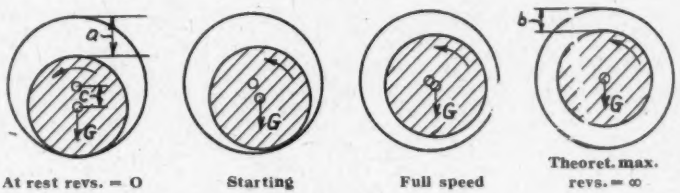

Fig. 1.—(a) Clearance (double) static.
(b) Uniform clearance = thickest film for infinite revolutions.
(c) Variable centre distance between journal and bearing.
(G) Weight of journal + fitted components.

low to diminish the internal oil friction which is increasing the temperature of the bearing. Temperatures above 75°C. are dangerous : they may cause deterioration of the working conditions of shaft and bearing. Further the deformation by heat has an unfavourable influence on the seat in the housing. Then the favourable centralising action of the high speed is counteracted by the escape of the thinnest oil. Ordinary good machine oil has a viscosity of about 300 Redwood at 30°C. reduced to approximately 100 Redwood at 60°C. The thickness of the oil film depends further on the clearance between journal and bearing. This clearance corresponds to the selected running fit which is itself determined by the degree of accuracy to be produced by the machine tool. Experience has shown that close running fits (.0005″) with ordinary ground surfaces give more trouble than wide ones. Yet on the other hand, we cannot allow too wide running fits for the main bearing on account of the resultant vibration and lack of accurate guidance. Thus we have the contrasting conditions that for low speeds and heavy cuts (e.g. big cutting forces for roughing), the temperature of the plain bearing remains

low, whereas for high speeds with small cutting forces for finishing cuts, the temperature is dangerously increased. Another decisive factor is the correct choice of the bearing material. Babbit, lead bronze and similar alloys seem to adapt themselves excellently to the deformed shape of the main spindle. This adaptation decreases the unit pressure and avoids particularly dangerous pressure at the corners.

On a standard S.A.E. oil testing machine load tests were made with 950 r.p.m., oil used M.S.782, viscosity 150 seconds at 210° (99°C.) on three bearing surfaces of different finish. The following results were obtained :—

	Surface		Total Load
	Machined	Smoothness Micro-inch	For oil-film failure Pounds
1	Ground	22 to 28	71 (average)
2	Partial superfinish	8 to 10	153 ,,
3	Superfinished	1 to 2	217 ,,

Surface No. 3 of 1 to 2 micro. in. (r.m.s.) would require over three times the pressure than the ground surface (217 : 71 lb.) before oil film failure.

The oil film between the ground surfaces was measured with .00085 in. thickness when scoring occurred, against .00031 in. between the superfinished surfaces without failure.

Some estimate of permissible bearing loads can be made from the following data :—

Metal	Pressure lb./sq. in.
Hardened crucible steel on steel	2000
Hardened crucible steel on bronze	1200
Unhardened crucible steel on bronze	800
Mild steel with smooth compact surface on bronze	500
Mild steel with ordinary ground surface on bronze	400
Mild steel with ordinary ground surface on white metal...	500
White steel on cast iron...	300
Cast iron on cast iron (journal bearings) ...	100

Operating conditions, lubrication methods and surface quality are among those items which influence the above figures.

The load carrying capacity of a bearing is limited by the thinnest oil film that can still operate hydraulically. *Research* shows that halving the oil film should double the load-carrying capacity of a bearing.* The oil film thickness is limited only by surface irregularities.

It would be possible to adjust the clearance of the bearings with special devices (Fig. 2) for the varying speeds, but this ought to be avoided. One cannot ask even an experienced and careful crafts-

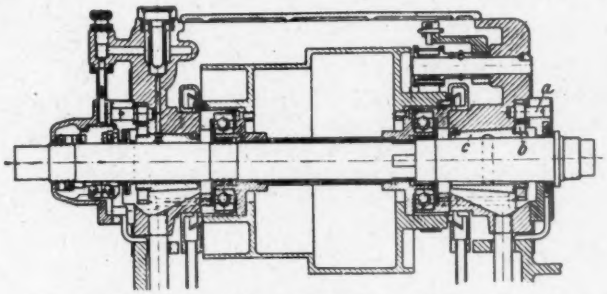

Fig. 2.—Spindle with device for adjusting the clearance of the bearings.
(a) Adjusting pinion.
(b) Nut with external teeth and internal thread.
(c) Bearing to be adjusted by thread and taper.

man to be adjusting the main bearings continually, when he has to turn first the big diameter of a piston of a Diesel engine and afterwards the small diameter of the rod on which it is pressed. The same adjustment must be kept for all conditions.

The design of machine tools cannot be considered as a single subject in the same way as that of Diesel engines, steam turbines, electric motors, etc. The varieties are too many; the working conditions are not comparable. Take as examples a big vertical boring and turning mill of 35 ft. swing with cutting speeds from 10 to 900 feet/min. making between 0.3 to 30 r.p.m., and a small internal grinder with an abrasive wheel of $\frac{1}{4}$ in. dia. running at 60000 r.p.m. for 4000 feet/min. peripheral speed. In these two extreme cases the bearings are of absolutely different kinds, so that the main spindle problem cannot be discussed for both at the same time.

However, the two principal designs are:

(1) The plain bearing and journal.
(2) The ball or roller (antifriction) bearings.

* A. M. Swigert Story of Superfinish 1940, *p.* 549.

By the improvements of the high speed tools the number of revolutions increased considerably and with it the circumferential speeds of the spindle, consequently the working conditions in the bearing. Therefore one would prefer ball and roller bearings in a great many cases. This is not only necessary to increase the efficiency of the machines but also to overcome lubrication difficulties. Special efforts are made to keep the plain bearing, particularly for machines such as the lathe and the grinders on which very fine surfaces are to be produced without chatter marks.

It may be mentioned that the hardened races, balls and roller, have practically no wear so that the centre distances of the gears positioned by such bearings are kept indefinitely correct.

(1) The Plain Bearing.

When the axis is horizontal, e.g. in the lathe, the cutting pressure P_c (Fig. 3 a, b,) operates generally towards the upper shell in the opposite direction of the weight of the spindle P_G. The weight of the spindle which has been increased by the parts in connection with it, may be much more than the pressure of a finishing cut but much less than that of a roughing cut. In any case, for idle

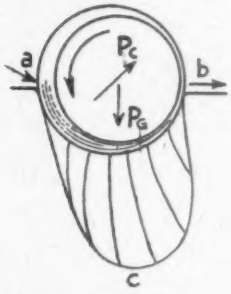

Fig. 3a.—Oil Wedge.
(a) Entry.
(b) Outlet.
(c) Pressure maximum.
P_G Weight.
P_C Resulting cutting force.

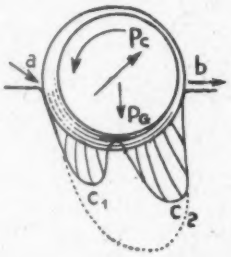

Fig. 3b.— Detrimental effect of Oil Grooves.
(a) Entrance.
(b) Outlet.
C_1 and C_2 Two small maxima of pressure.

Direction of cutting opposite to hands on a watch.

running a displacement in the direction of P_G takes place which fixes clearly the position of the oil wedge for normal anti-clockwise rotation. Only if the working conditions of the plain bearing are known, one can fix the position of the oil grooves correctly. Nowadays it is quite certain that internal oil grooves in the surface of the bearing which takes up the pressure are not only useless but

detrimental. They diminish the available surface of the bearing taking the pressure. On the other hand the oil pressure which lifts the shaft of the bearing will not become effective because the lubricant can flow off through the grooves.

In general it is sufficient if the edges of the two halves of the bearing are chamfered at that side of the joint, where the oil enters at the point of lowest pressure; leaving about $\frac{1}{4}$ in. unchamfered on both ends as a longitudinal oil seal.

When reversing, the oil grooves, which are correct for normal rotation are now in a much more unfavourable position and it is evident that it is not possible to design an oil supply without artificial pressure which can be used under load from any direction. The "Universal" bearing can only be designed for forced lubrication.

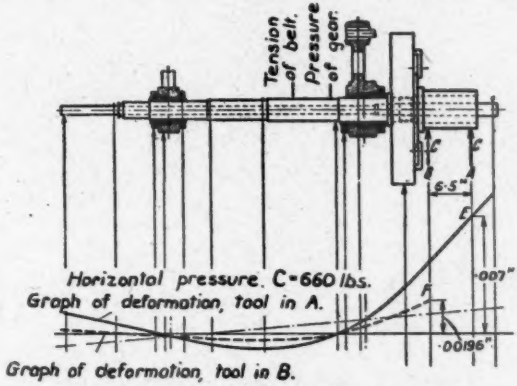

Fig. 4.—Deformation of spindle doing chuck work.

Tension of belt. **Pressure of gear.** **Horizontal force.** ——Deformation line: tool in A. – – –Deformation line: tool in B.

As for machine tools, there is another difficulty. The forces while cutting metals differ from the smallest cutting force for fine finishing to the heaviest forces for roughing. The bearing must be strong enough to stand those varying forces; not only as bearing in the ordinary sense but as an element of design which is able to guarantee the precision and the geometrical shape of the piece which has to be manufactured "round" while being drilled and turned, or "plane" in milling and planing. The bearing of the machine tool is thus guiding in the fullest sense of the word. The following tests show clearly how the shape and the position of the shaft in the bearing is changed. For a bearing rigidly fitted—without automatic alignment—the first important question is that of deformation:

(a) by machining freely chucked specimens (Fig. 4).

(b) by machining between centres (Fig. 5).

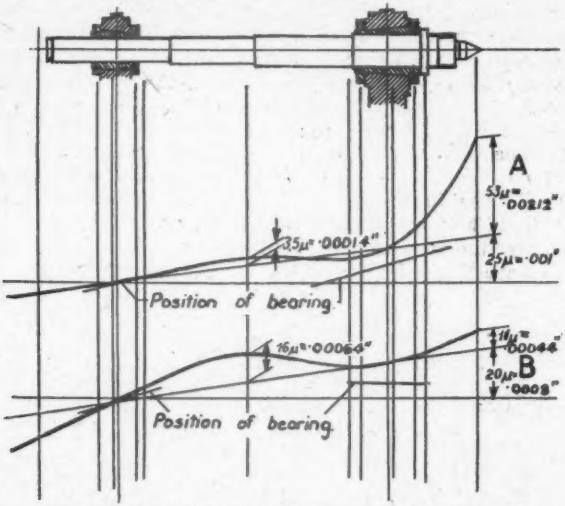

Fig. 5.—Deformation of spindle by work between centres.

For this purpose the spindle deformation of a medium 6 h.p. lathe was measured. The spindle had a front bearing of $3\frac{1}{4}$ in. diameter, the distance between front and rear bearings was 30 in. and the vertical force P_c (power component) at the tool was 1 ton. In the case of the chucked specimen the cutting force acted at a distance of $6\frac{1}{2}$ in. from the front end and for the specimen turned between the centres in the middle of a shaft 60 in. long. Fig. 4 shows the deformation of the spindle for chucking work, Fig. 5 between the centres.

The chuck work has a much worse influence on the deformation of the spindle and the pressure within the bearing than the work between centres. It is essential to note that the spindle is always bent in the front bearing, which causes pressure on the corners (Fig. 6). This may break the oil film at the corner, and then

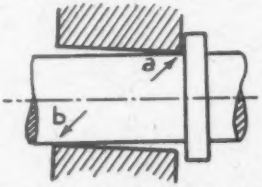

Fig. 6.—Corner pressures due to bad alignment of spindle and too much clearance.

the bearing seizes. High pressure on the front edges may also cause a bad position of the spindle relative to the bearing.

The fundamental condition for the correct theoretical calculation based on the uniform distribution of pressure is destroyed. The front edge "a" of the bearing (Fig. 6) gets too much pressure and will tend to seize and score if the metal of the shell does not give way elastically so that a much bigger surface than the front edge will accommodate itself to the shaft. Bearings made of white metal and of bronze do that. Bearings of cast iron or hardened steel do not adapt themselves and cannot be used as a rule for machine tools. If a bearing is rigidly fixed in its housing it imposes on the shaft a bending moment which is generally undesirable. To avoid

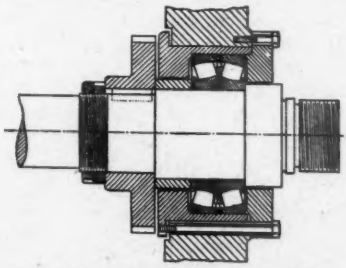

Fig. 7.—Self Alignment. Self adjusting Roller bearing with spherical thrust race (British Patent 337237 John Lang).

this one can take self-aligning bearings (Fig. 7) or short plain bearings (comp. Fig. 18).

With machines used only for fine finishing work of the highest precision (diamond turning lathes, grinding machines, etc.) the forces which distort the shafts are very small. No oblique displacement of the main spindle of these fine machines is permissible; only manufacturing tolerances of 0.0001 to 0.0004 in. are allowed. That is why the bearing must avoid any deformation or displacement of the shaft which must itself be very rigid. The highly loaded journals of the main spindle shaft adapt themselves in the bores quite differently. They are in a much worse condition than is generally thought and yet these most important bearings work well for many years. For these cases one can but design (not calculate) with the help of coefficients of specific pressure which have to be chosen so small that all deforming forces, especially the pressure on the front edge, are allowed for.

As far as lubrication is concerned it would be best to use self-aligning bearings. This would prevent the bending effect of the bearing under cutting stress already mentioned. To lessen the deforma-

tion, the shaft should be designed still more strongly (of greater diameter) than in general machine design. This again increases the circumferential speed. Spherical or barrel shaped races for ball and roller bearings may help to fulfil the conditions for self-alignment. The correct choice of the lubricants (viscosity), the clearance and the increase of the diameters does not offer any difficulty with reference to the previous calculation ($p \times v$). The increase of diameter is even desirable on account of the passage of bar work through the spindle bore.

The deformation of the spindle must be calculated assuming that the spindle is freely supported in its bearings. Within the length of the bearing the deformation should be less than the oil clearance to avoid pressure at the edge in any case. This demand is more easily fulfilled with short bearings which give pure liquid friction than with long bearings calculated according to the formula $p \times v$. The self-alignment of the spherical roller bearing races and the "Timken" floating ring permits the axis of the bearing to adapt itself obliquely according to the elastic line of the spindle. Then the actual stress corresponds to the free suspension of the spindle.

An additional deformation of the spindle might result from an axial load due to the feed force. This stress is only of secondary importance. It is the smallest of the cutting forces in the lathe and corresponds to the small axial force in the milling machine. Considering the axial load on the spindle (buckling load) it is practically negligible if it is taken by the front or the rear bearing of the spindle. Often the second solution is chosen on account of the greater accessibility and the easier adjustment and, further, the much smaller diameter of the rear end. The result is a smaller loss by friction.

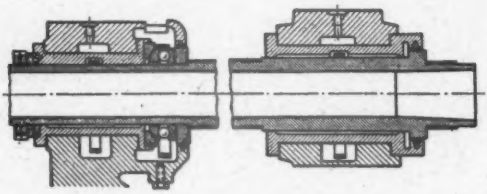

Fig. 8.—Ball thrust bearing on rear end.

In principle, (Figs. 8 and 9) the taking of the axial load by the front bearing is to be recommended as well as the taking of the pressure of the last gear (bull wheel) as near as possible to the front end of the spindle. The bending length is decreased practically

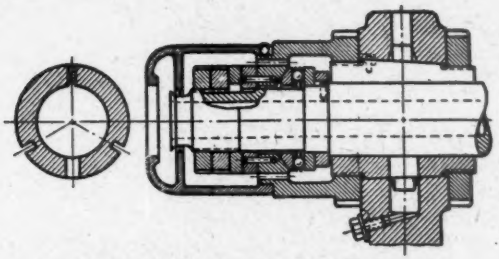

Fig. 9.—Another type of rear thrust bearing

to zero and other deflections of the spindle which might take place, are automatically suppressed.

To avoid an extension of the spindle by heating it is correct to take the axial thrust on the front bearing. Then the spindle may

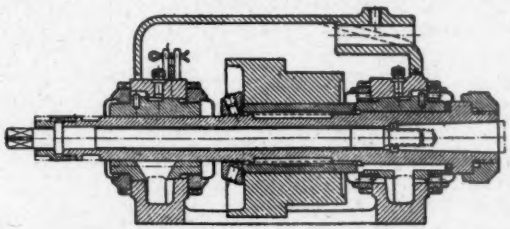

Fig. 10.—Thrust bearing for small lathe.

extend without difficulty towards the rear ; otherwise the extension of the spindle influences the work-piece (distances of shoulders).

In the small lathe (Fig. 10) the axial force is taken by a flat washer, while with a heavy lathe this is done by a front ball thrust bearing placed in front of the main plain bearing (Fig. 11). These

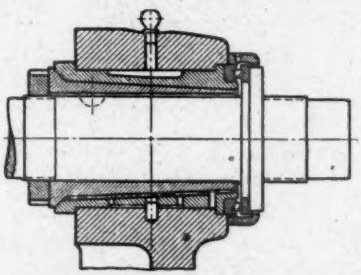

Fig. 11.—Ball thrust device on front bearing of heavy lathe.

various arrangements emphasize the fact that the method of taking up the axial thrust is a very important feature of the design, the strength of the spindle can easily be made ample in any circumstances.

It is understood that the material for the spindle must be of high quality, combining great rigidity and long life. The main spindle is one of the most expensive parts of the machine tool and must last for the whole life of the machine. For small and medium sized machines case hardened steels are used. The surfaces of the bearings are ground, honed or lapped. The length of the spindle is limited by the depth of the usual furnace. For heavy machines the very long spindle can rarely be case hardened, but the favourable combination of big load, and slow speeds allows to use successfully, a heat treated hard alloy steel of high tensile strength. Otherwise it will be necessary to shrink hardened bushings on the soft spindle.

The case hardened spindles remain soft in the core and are bored after having been hardened. One begins to grind the journals and then to bore the soft core to avoid difficulties in straightening hollow hardened, but warped spindles. Therefore one can use for hardened journals only such qualities of steel which produce both glass hard surfaces and a soft core. That is the case with kinds of steel having not more than .15% C. Nickel alloy steels of the following analysis are to be preferred :—

N	C	Cr	Ni	Mn	Tensile tons/sq"	Brinell	Remarks
I	.10–.17	.2	1.5	.5 max	45–55	162	small machine case hardened
II	.10–.17	.75	2.5	.5 max	55–65	206	medium machine case hardened
III	.27–.35	0.75 ±.2	3.5 ±.25	.4 to .8	90–100	240	heavy machine normalised

The depth of cementation of the surface of a casehardened spindle is in general between 0.03 and 0.04 in. It is necessary that the hardened layer is much deeper all round the circumference than the material allowance for the grinding machine (0.015 in. of diameter). The spindle bearing will get oval in a very short time if care is not taken to provide sufficient case depth to avoid penetration when grinding.

With the milling machines the tool rotates with the spindle (Fig. 12). Using the taper arbor supported by the overhanging arm the conditions for the deformation of the spindle are somewhat the same as for work between the centres of a lathe. There is a driver, but axial forces are only created when using facing cutters or milling cutters with helical flutes.

The action of the forces in using milling cutters with inserted blades (Fig. 13) corresponds to those of chucked work with lathes. The spindles of milling machines can, therefore, be calculated somewhat similarly to those of lathes.

Quite different conditions exist for drilling machines. Supposing one uses centred tools such as drills, counterbores, reamers, taps, etc., a pure torque without any eccentric bending force will be observed.

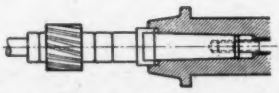

Fig. 12.—Mounting of tool in spindle of milling machine.

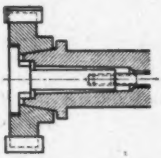

Fig. 13.—Cutter head mounted directly on spindle nose of milling machine.

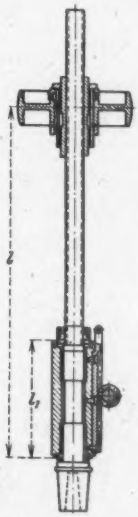

Fig. 14.—Spindle of large drilling machine.

(Fig.14). A small additional bending force will occur only if the tools are inaccurate, e.g. eccentrically ground. The effect of this force on the spindle in negligible.

With the milling machine and the lathe, the last transmission gear should be arranged as near as possible to the front bearing to decrease as much as possible the amount of twist under torsion (comp. Fig. 27a). This is impossible with the drilling machine on account of its design. One must even calculate with the maximum length (l) under torsion (Fig. 14) if the drive

is at the uppermost end of the spindle, i.e. if the bore is machined at its extreme end. The spindle must be made sufficiently strong so that the stress due to the torque can be taken without difficulty. Compression stresses (buckling) caused by the strong feed force have no influence on the main spindle as the sleeve takes the force directly behind the drill chuck. Though the speeds and forces vary greatly with all machine tools, attempts must be made to realise the advantages of pure fluid friction [absence of wear, decrease of friction and vibration (damping)]. The con-

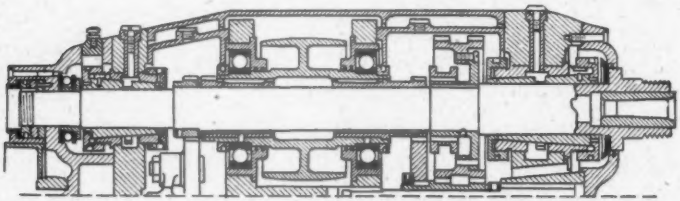

Fig. 15.—Headstock of a diamond lathe (Kaerger) with plain cylindrical front bearing for 3000 R.P.M.

ditions of the design are decisive. High speed (v_h) together with small unit pressure (p_s) causes in the plain bearing a thick oil film and creates just the fluid friction required.

Low speed (v_l) with high unit pressure (p_h) using oil of a low viscosity create an eccentric position of the shaft and a thin oil film. Consequently the danger of running half dry is increased unless the running surfaces are very smooth. The great variations of the number of revolutions and of pressure in the invariable combinations $p_s \times v_h$ for finishing and $p_h \times v_l$ for rough turning set by the fixed power of the motor have limited the use of the plain bearing. The reason for it is the impossibility of changing each time its adjustment to obtain the best lubrication conditions.

Plain bearings suffice very well for rather high numbers of revolutions from 400 to 3,500 r.p.m., even with close running fits, just if vibration had to be prevented at all costs, as e.g., with lathes for fine finishing work with cemented carbides or diamonds (Fig. 15). An advantage of this design is that there is no thread on the front taper bushing. The bevelled clamping surfaces of the adjusting nuts cause the bushing to be more firmly tightened against the bore of the housing. This design eliminates the possibility of the split bushing collapsing when being tightened or losing its round shape. Another disadvantage is that the distance between the front face of the journal and the spindle nose gets rather large on account of the wide adjusting nut. Besides, the precision of such a bearing

is limited by the smallest admissible clearance (close running fit) which is about 0.0003 in. for 1 in. dia. while the oil film for ball bearings may be decreased to 0.0001 in. or still less (preloaded). The acceptance specifications* for machine tools give reasonable limits for the main bearings of lathes, capstan lathes, grinders by the performance tests. One cannot exceed the natural laws of possible lubrication. The bearings of this lathe were recently improved by adding external threads to the nuts which meshed with bushings on the housing. The result of this is that the design is more rigid.

A specially good effect is got with the automatic turret lathe (Fig. 16) used for the manufacture of precision parts in the watch-making industry. The admissible tolerance, e.g. for the escapement spindle of 1 mm. (= .040 in.) diameter is $\pm$ .00025. The spindle

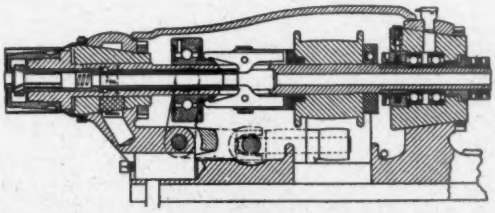

Fig. 16.—Headstock of automatic turret lathe. (Petermann-Moutier). Main spindle $\frac{1}{2}$ in. diameter, 10,000 R.P.M. Nitrided steel. Babbitted bronze bearing.

runs at 10,000 r.p.m. and is made of nitrided steel, with hardened bearings ground and lapped. The machine has a taper front bearing (22 mm. dia. $= \frac{7}{8}$ in.) made of babbitted bronze and is adjustable.

The rear bearing consists of a two-row ball bearing.

The essential feature of the plain bearing is the damping quality, which is necessary for work without vibration marks, and its supreme simplicity: one spindle and one bushing: one single pair of simple elements machined with the highest precision and the perfection of surface by lapping or honing the spindle and the bore. Besides there is the possibility of adjusting the main bearings of the spindle by hand scraping or polishing. Such hand operations even by skilled craftsmen are false because they may ruin frequently the perfect cylindrical shape which has been obtained on first rate machines by fine turning, grinding, honing, lapping or superfinishing. The housing should, if possible, be made solid (Fig. 17), because e.g. during turning operations, the stress of the cutting is usually directed against the top shell. If the housing consists of two parts

* Acceptance Test Charts—Part I and II of the Inst. of Prod. Eng. and Mech. Eng.

only the clamping bolts which hold the cover have to take up the main cutting force. Therefore the clamping bolts and nuts must be rather strong and manufactured with great care to avoid any vibrations. During the acceptance tests the main spindle should turn, as it is then concentrically lifted. The admissible out of round deviation of the spindle (comp. acceptance tests of I.P.E. for lathes

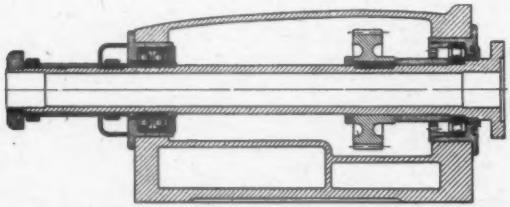

Fig. 17.—Strong housing of turret lathe with roller front bearing and self-aligning ball rear bearing.† (H. W. Ward & Co.). Action of forces against upper part of housing.

test No. 25) is only 0.0005 in. maximum. Therefore the change of the thickness of the oil film is not negligible. However, the position of the main spindle during the work is of great importance. The errors are increased by the wear of the upper bearing (clearance) and by the wear of the guides (misalignment, e.g., of the tailstock) downwards. The shape of the solid plain bearing may be :—

(1) Cylindrical inside and outside (Figs. 8, 18, and 21a–d).

(2) Cylindrical inside and taper outside (Figs. 2, 10, 15, 16, 21, 22-24, and 30).

(3) Taper inside and cylindrical outside (Figs. 11, 25, 26, 27, 27a, 28, 29, and 29a).

(1) Cylindrical bushings are very often used for the rear-bearing, and with rather big machines even for the front bearing. They consist of two parts to allow readjustment. It is necessary that they are always very well fitted to the housing (easy push fit). They must be well secured against turning by a pin or a key to give the correct position to the oil grooves which must never lie in the zone of the load.

There is no possibility of adjusting the bearings if they are made solid. However, experience has shown that plain cylindrical bearings have a long life especially for the rear bearing with negligible wear. Of course, they must only be used to secure the correct concentric guidance of the spindle. If the rear bearing has to exercise a deflecting influence against a strong load on the spindle (see Fig. 4 and 5), the consequence would surely be a pressure at the

edges combined with wear. In this case one must choose an adjustable design (Fig. 15) even for the rear bearing.

An improvement in plain cylindrical bearings takes the form of homogenised bronze of copper tin alloys (Carobronze). These bearings can support a very great unit pressure and they are very resistant to wear. Their great load-carrying capacity gives the

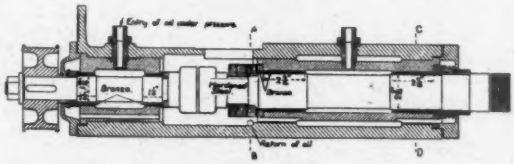

Fig. 18.—Plain bearing. Short length of Carobronze. 2000 to 3000 R.P.M. Clearance of oil 0.002 in. to 0.003 in.

possibility to design short bearings which are of similar dimensions to roller bearings, or even smaller, particularly with large diameters. If the loading capacity of such bearings is completely exploited, they get a coefficient of friction which nearly equals that of roller bearings (Fig. 18). An adjusting device is not necessary because they work for a very long time with negligible wear. An indispensable condition is that the spindle and the bushings must be made according to the best methods of manufacturing to get the least permissible clearance and the full exploitation of the load carrying surface. The bearing surfaces of the spindle which are glass hard must be well lapped, honed or superfinished (1 to 2 micro. in.-ave) and the bearings themselves should have either the finest diamond finish or microfinished quality (2 to 3 micro-in.). Case hardened or nitrided steels for the spindle have better running properties than heat treated alloy steels. The working capacity is lessened by too much chrome being used; even nickel is unfavourable.

For most cases regarding machine tools lubrication by rings, wicks and drop oilers without special designs to diminish the heat will suffice if the oil grooves are made with special care.

The technical data for Carobronze alloy are: about 91.2% copper, 8.5% tin, 0.3% phosphorus; using new metals only without any impurities as, e.g. zinc, lead, aluminium, stibium, iron, etc. Specific weight 8.86; coefficient of extension by heat = 1.75×10^{-5}.

The unit pressure of the bearing is given between 1400 and 5000 lb./sq.in., the coefficient of friction from 0.001 to 0.005.

The relations between the coefficient of friction, increase of temperature in the housing, running speed, unit pressure and abso-

lute stress are shown in Fig. 19. They have been noted during actual running tests with Carobronze (Kammerer-Charlottenburg, 1920).

(2) Using a bushing externally taper with a cylindrical bore (Fig. 15) the manufacture of the spindle is simple and the bore can be adjusted.

The adjustability of the bearings has the great advantage that after fitting the bearing into the housing clearance for oil can be

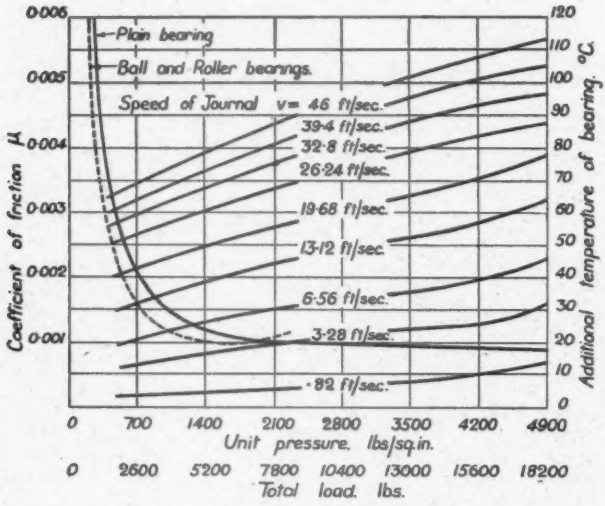

Fig. 19.—Diagram of application of Carobronze.

regulated according to the acceptance specification for precision. Further, it allows us to make up for the wear which shows gradually in the bearings.

The adjustment is made by using mechanical force on the slotted shell in general by a combination of screw and wedge. The deformation of the bearing remains final with the result of smaller interior diameter (Fig. 20). This process has long been used with good success, but one must not think that such a violent deformation of the bearings produces surfaces which are really cylindrical in the interior, nor really taper on the exterior. No doubt slitting a bearing entirely at one point and notching it at a number of points (e.g. Figs. 15, 21), will produce a polygonal surface which is neither entirely cylindrical at the interior, nor entirely taper at the exterior,. But the deviations correspond to a very small diminution of the interior diameter of

0.0002 to 0.0005 in. If one makes a full size drawing of the (four) circular segments around the unchanged axis there will be scarcely any difference if one compares them to the exact circle. This result is favourable as the fitter making the adjustment is compelled to rescrape the whole interior surface which carries the load after each adjustment and to correct the oil grooves as well. As there is the question of very small deflection there will be no other means than to make the final adjustment by hand. The exterior

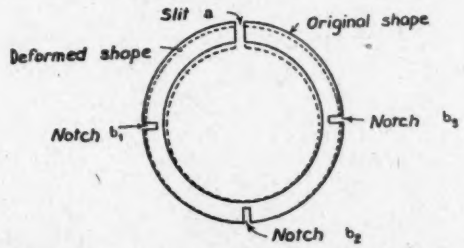

Fig. 20.—Adjustable Plain bearing. One complete slit, three notches.

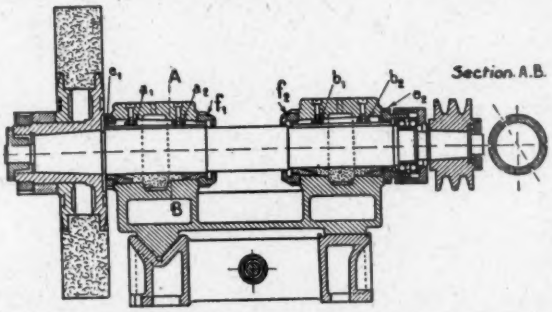

Fig. 21.—Plain bearing for grinding machine with one slit and two clamping dovetail slots (a_1, a_2, b_1, b_2), nuts (e_1, e_2) and counter nuts (f_1, f_2).

taper which, after being bent, touches only the bore of the stationary housing on a very small surface or points is generally not rescraped at all. It is supposed that the deformed external taper of the bush will be rather well fixed by locking the two nuts e_1 and e_2 and the counter-nuts f_1 and f_2 (Fig. 21). Generally this is wrong as even very slight deformations are much worse with the taper than with the cylinder. The bearing can now make small movements in the housing. This is the reason for vibrations which are often difficult to find. The designer tries to find an improvement of the

fixing of the cone in the housing. A design often used has two dove-tailed wedges (a_1, a_2, b_1, b_2) which are pressed in the slot of the bushing before its final interior adjustment. (Fig. 21). The consequence of this is that the taper surfaces which are bent internally are now bent back forcibly at two spots at least. The bearing is now pressed tight enough by the two transversal forces of the wedges and the two longitudinal forces of the nuts in the housing so that for moderate cutting forces the vibrations are eliminated.

It would be correct to regrind the contracted and internally trued bearing on a corresponding cylindrical arbor to the exact shape of the external taper. But this creates some difficulties in fixing the bearing on such an arbor. Generally on account of the very small quantities in question the above mentioned procedure of

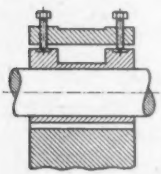

Fig. 21a.
3 line support.

"Mackensen" bearing.

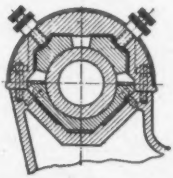

Fig. 21b.
3 surface support.

several small violent deformations is accepted as sufficient and has proved satisfactory. The whole is an interesting case of theoretical demands and their practical execution.

Horizontal bearings have the full slot generally on top in order that the oil does not escape. That is correct only if the resulting cutting force is directed downwards. In no case should the slot be in the zone of pressure—as is still found with many lathes.

With spindles of *grinding machines* (Fig. 21) the considerable dead weight of the spindle must be taken into consideration when the position of the slot is determined. The weight of spindle and abrasive wheel will in general be much more than the resulting grinding force which is not more than 150 lb. even for very heavy machines with an abrasive wheel of 32 in. diameter and 3 in. wide.

Figs. 21a-d show bearings which are internally and externally cylindrical. Their adjustability is differently made. Fig. 21a, b, c, are mechanically adjusted, Fig. 21d hydraulically.

The Mackensen bearing (Fig. 21a) has a bushing which is intentionally deflected by three screws so that the support is in the form of three lines (better small surfaces) uniformly distributed around the circumference of the bushing.

The second Mackensen bearing (Fig. 21b) is made of three separate parts and has two upper pieces which are independent from the bearing-shell, forming a three surface support, which is preferable to the line support. Therefore it will carry a much heavier load than the bearing, (Fig. 21a). However, the fundamental idea is

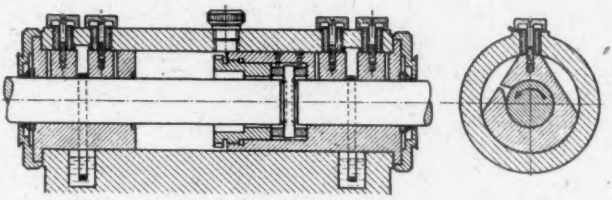

Fig. 21c.—Partially slit bearings adjusted by press-screws.

the same for both, namely, to adjust a bearing from three equally distant, uniformly distributed points.

The design (Fig. 21c) uses bearings which are only partially slit and adjusted by press screws.

The particular design (Fig. 21d) used for external grinders replaces the hand adjustment, which relies on the skill of the fitter, by an automatic adaptation of the upper shell loaded by the hydraulic pressure of a fluid. The four pistons—two for the front and two for the rear bearings—are loaded by the common load

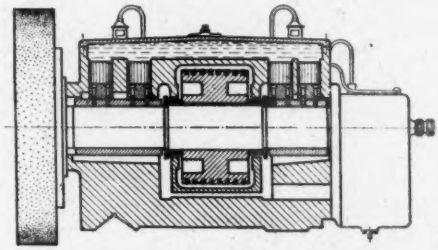

Fig. 21d.—Plain bearing. Self adjusted by hydraulic pressure. (Churchill & Co.)

distributing fluid. The uniformity of the pressure depends on the uniformity of the fluid supply by the pump. Patents are taken on back-pressure valves to secure a uniform supply and to reduce any prejudicial effect of fluid vibrations.

If the working pressures are very small, one may even use the

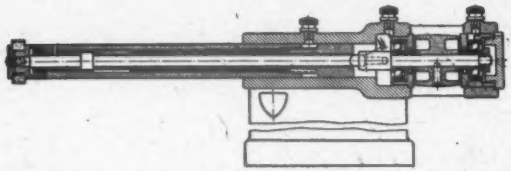

Fig. 22.—Internal grinding spindle (20,000 R.P.M.) with plain front bearing of hardened steel.

Fig. 23

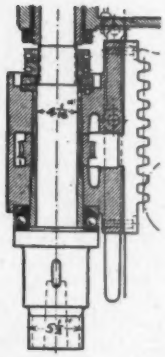

Fig. 23.—35 H.P. Vertical drilling machine. Diameter of twist drills between ⅛in. and 4in.

Fig. 24

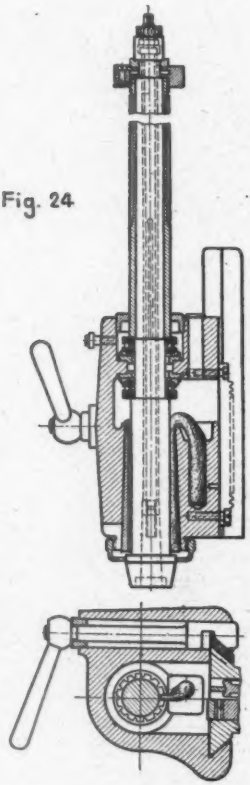

Fig. 24.—Vertical milling machine. High speed 5,000 R.P.M.

plain split bearing (Figs. 16, 21) with very great circumferential speeds. The journal and bearing must be made of hardened (nitrided) steel and well lapped (2 micro-in. and less). The oil clearance must be reduced to the permissible minimum using an extra fine spindle oil.

Such a split front bearing made of hardened and ground steel was used for the internal grinding apparatus which runs at 20,000 r.p.m. (Fig. 22).

It should be possible to avoid unilateral stress on the spindle or to reduce it to a minimum, as is the case with vertical drilling machines. Then a reliable supply of oil will be secured and high speed may be allowed even for normal materials, i.e., spindle of hardened steel and bearing of bronze or of babbit. Fig. 23 shows the main spindle bearing of a heavy drilling machine (35 h.p.) which can be fine adjusted by a split bushing made of bronze, externally tapered and internally cylindrical. The adjustment is made by worm and worm-wheel, which is internally threaded meshing with the thread of the taper bushing. It has done useful work of all kinds (up to 35 h.p. drive) during more than 25 years.

With the journals of milling machines we have not such a balanced load as with drilling machines. On the contrary the milling cutter is working in most cases unilaterally. Then bending forces affect the bearing. But with the small vertical machine the stress is not great. Therefore a taper bearing has proved suitable on the main spindle of a small vertical milling machine (Fig. 24) which makes 5,000 r.p.m. This is split and notched six times and lubricated by a wick. The adjustment of the bushing is done somewhat as shown in Fig. 23, but as the bushing is very small it can be done by a shouldered bolt with which the taper bearing can be pressed into the housing.

The bearings shown here have been taken from machines which have only been designed or put in use since 1934/5, or are from machines which have been long in use and given good results. Therefore these may be considered as modern machines. They prove that the people in favour of the plain bearing constantly use this old design and try successfully to improve it. They even seem to overcome the difficulties which arise by the use of super high speed tools. The cylindrical bore is even to be preferred as it does not in the least disturb the axial displacement of the main spindle. It facilitates also the side adjustment of the gears and the pulleys In order to avoid the taper bore (Fig. 11) in the housing an intermediate bushing has been added in some designs. This bushing is fixed externally in the cylindrical bore of the housing and takes up the external taper of the bearing. (Fig. 15). However, by this additional joint the rigidity of the complete spindle bearing is decreased. The fewer the number of elements

used in the plain bearing the more reliable it is, and the smoother will be the working of the machine.

(3) While using a taper journal for the main spindle (Fig. 25) either only in front or in front and in the rear (Fig. 26) the external shape of the bearing may be cylindrical. It can then be pressed into the housing with an easy push fit without clearance. As to rigidity, this design is good. It has a minimum of components and keeps its alignment exactly. But there is one disadvantage; when a bearing is overhauled, e.g. by scraping, the spindle changes its longitudinal position and moves all the gears and other attached

Fig. 25

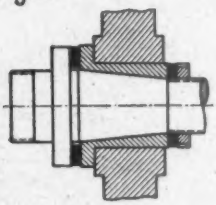

Fig. 27

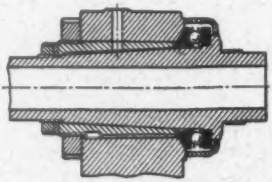

Fig. 26

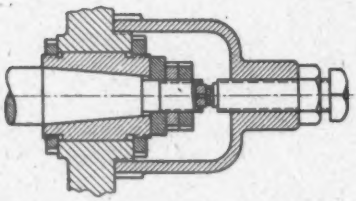

Fig. 25.—Front taper bearing with thrust washer.

Fig. 26.—Rear taper bearing. Adjustable bushing of bronse. Axial thrust absorbed by central screw.

Fig. 27.—Taper front bearing. Taking up the axial thrust by roller bearing.

parts backwards. To readjust these, when required, correct provision must be made. Therefore the designer makes the counter bushing in the housing adjustable and supports the spindle from behind (Fig. 26). The slant cone (mostly 1:10) can only guide transversely. As soon as the taper is pressed into the bearing in the longitudinal direction it will easily seize. Therefore it is necessary to have an adjustable thrust bearing which can be reliably adjusted and it is advisable to join it directly with the taper journal of the bearing. The simplest way to take up the longitudinal force is a thrust washer or a ball thrust bearing fitted between the

shoulder of the spindle and the front surface of the bearing or housing (Figs. 11, 25, 27). The thrust washer assures the necessary clearance of oil in the taper bearing, but its width must be accurately adjusted after each rescraping of the taper.

In the fast headstock of the " Oerlikon " lathe (Fig. 27a) the axial thrust on the spindle is taken up in both directions by ball bearings which are fitted on the spindle behind the second gear drive. The

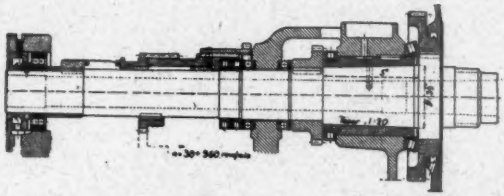

Fig. 27a.—Headstock of heavy lathe (Oerlikon) for 3 to 950 R.P.M. Taper front bearing with two ball thrust bearings.

support for the roller races is rigidly connected with the front taper bearing by a common housing and forms, so to speak, the single body of a very strong bearing. The characteristical feature of this headstock is that the bull wheel is fastened directly on the flange of the spindle-nose in front of the main bearing. The result is that the spindle is nearly freed of all twists even when the strongest cutting forces are acting. The spindle works therefore without any vibrations. Oerlikon recommends as lubricant " Gargoyle

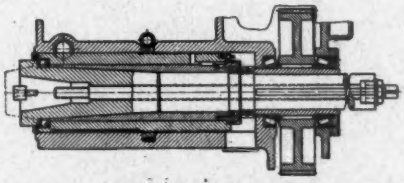

Fig. 28.—Plain bearing with fine adjustment by worm, worm wheel and thread for heavy milling machine.

Velocite Oil " to avoid the overheating of the bearing working at high speed (1,050 r.p.m.).

The taper bearing must be very carefully fitted. Errors in the shape of the taper, internal or external, mean that the taper of the journal is only touching at some points and does not support sufficiently. Sometimes two types are combined, with one of 45° to take the axial thrust, and the other of from 1:10 to 1:12 to act as journal

(Fig. 11). The two inclined lines should then form tangents to the diagram of pressure—distribution (Schiele's parabola of antifriction). This design is supposed to promote very favourable working conditions. However, these two bevels must touch the bearing surfaces at the same time. They influence each other differently and their manufacture as well as their maintenance is difficult and expensive and stand in no relation to the practical profit.

If one chooses also for the rear bearing the taper form the exterior bearing must be adjustable in the axial direction (see Fig. 26) because the taper front bearing fixes the spindle axially.

With all these bearings the rotating hardened journal of the spindle which is equally loaded in all directions keeps its shape. On the

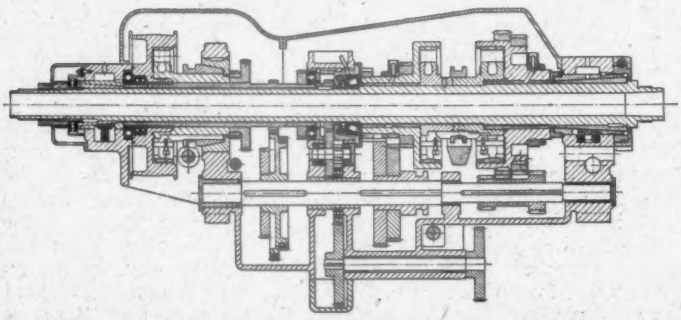

Fig. 29.—Turret Lathe (Gildemeister) taper bearing, bronze bushing pressed on spindle which turns in an external bushing of hardened steel which is axially adjustable.

contrary the bushing of soft bronze or white metal which does not turn, and which definitely fixes the alignment of the spindle, loses its round shape after some time on account of its unilateral load. Therefore the raw materials have been changed in the case of the automatic screw machine (Fig. 29). An exterior taper bushing of bronze has been pressed or shrunk on to the soft spindle. The stationary bearing is made of hardened steel. When the bronze bushing which rotates, is loaded, it is worn out uniformly in all directions and thus remains round. The wear may be compensated by axial adjustment of the bushing with a worm gear and an internal thread, the same as already seen with the heavy drilling machine (Fig. 23).

Fig. 29a shows the taper front bearing of a 20 h.p. heavy vertical grinder making 1800 r.p.m, with an abrasive facing wheel of 14 in. dia. The oil is forced upwards by the steep spiral cut on the outside of the taper. A ball thrust bearing in front takes up the large axial

force. The very accurate and fine adjustment which is necessary between the thrust ball bearing and the taper sleeve is made by worm, worm wheel and internal thread. These elements are locked when the adjustment is obtained.

Because a very high precision is required from a front bearing of a good machine tool, the oil clearance must be very small. It varies according to the size of the machine and the precision required for finished work. The above-mentioned small clearances (.0003 in.-.0005 in.) are generally sufficient for the requirements of safe

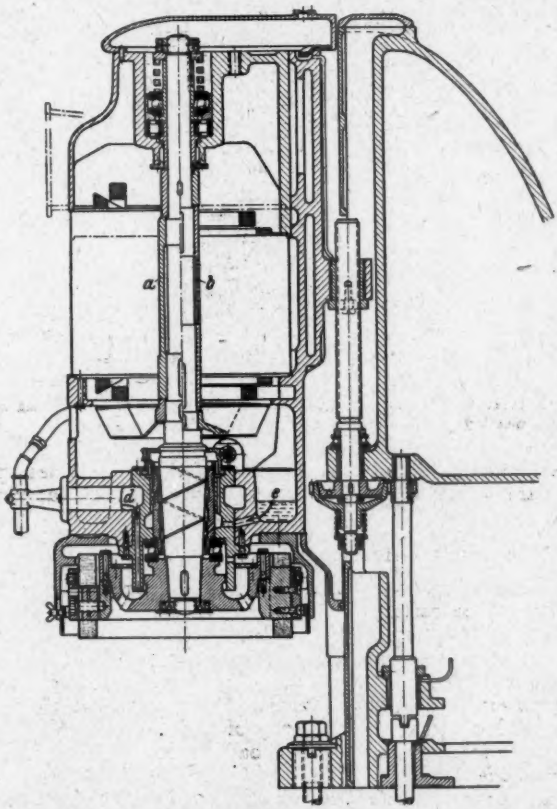

Fig. 29a.—Plain spindle of 20 H.P. vertical grinder. Taper front bearing, deep shoulder rear ball bearings.

lubrication. A fine spindle oil is wanted which has a viscosity of about 60 to 80 Redwood at 50°C. For finishing lathes and jig borers one even provides an oil clearance not surpassing .0002 in. If the temperatures of the bearing become too high a forced oil circulation must be installed or even a water cooling system.

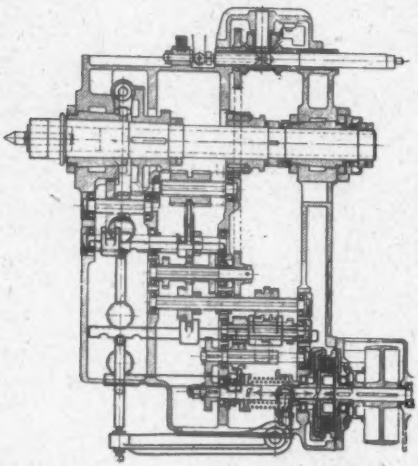

Fig. 30.—Headstock of lathe, with spindle in plain bearings. Ball and roller bearings for the secondary shafts (M. W. F. Magdeburg).

To assure the oil film in the bearings of these machines special designs are wanted to create and to secure the load carrying oil wedge.

2. Ball and Roller Bearings.

There can be no doubt that the number of revolutions of the spindle must be raised with the increasing improvement of the super high speed tools : Cobalt-Tungsten, Stellite, Cemented Carbide, Diamond. Plain bearings will not then be able to allow the required speeds up to 10000 r.p.m. for spindles of 3 in. dia. The consumption of power on account of increased friction in the plain main bearing will diminish the efficiency of the machine. All this will lead to the final introduction of the ball and roller bearings for high speed machines.

For all auxiliary shafts which do not need such high grade location as the main spindle, ball and roller bearings already dominate nowadays to decrease the friction, increase the efficiency (Fig. 30)

and secure the centre distances of gears. Ball bearings are used for lightly loaded machines, cylindrical and taper roller bearing, (e.g. Timken) for heavily loaded machines. As above-mentioned the plain bearing has sometimes been kept for the main spindle of small machines up to 10000 r.p.m. $\frac{7}{8}$ dia. of front bearing. (Fig. 16). We shall deal with the use of roller bearings especially for main spindles the development of which is at present in full swing.

The use of ball bearings for the main spindle is shown in Fig. 31, for a small Petermann high speed automatic screw machine : front diameter of spindle $1\frac{1}{4}$ in.

Ball and roller bearings are always composed of many parts. They have two races and a large number of rolling bodies (balls,

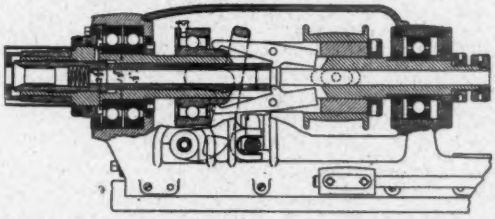

Fig. 31.—Automatic turret lathe. (Petermann-Moutier) 6000 R.P.M. Two ball bearings in front. One locating roller bearing with deep shoulders at rear.

cylindrical or taper rollers) which are separated from each other by a cage. Machine tools require balls or rollers and races of special precision and high uniformity because the bearings of the main spindle of the machine tool serve not only for the ordinary location but must always keep a very high degree of prescribed accuracy while machining. We have already mentioned before that the main bearing has to stand all kinds of loads and that it must as a rule equalise the deformations of the spindle under the cutting pressure. This is done *through a counteracting bending effect which does not usually come within the scope of the ordinary bearing.*

Even nowadays there are still some difficulties in getting ball or roller bearings of the required precision for the main spindle. One finds a way out of the difficulty in selecting for this purpose bearings which are particularly exact but which are naturally more expensive.

The principal and decisive advantage of the ball and roller bearings is that the clearance of the bearing can be reduced to a fraction of the oil clearance of an ordinary bearing even to almost nothing by preloading without the danger of seizing. An oil film of .0001 in. thickness which remains between the ball or the roller

and the races is not torn even by quite heavy pressures. Dry friction which would destroy the rolling surfaces at once is thus avoided. Therefore roller bearings under initial load (preloaded

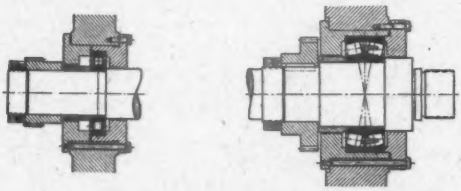

Fig. 32.—Spherical front bearing, self-adjusting; rear roller bearing. The front bearing is pre-loaded. (Comp. Fig. 7).

bearings) can be used, i.e. bearings practically without any clearance. The liquid friction of the oil film is evidently kept up in spite of this pre-load. This quality is explained by the fact that the ball or roller elements form entirely contained lapped bodies, not interrupted by any oil groove. The highly polished surfaces—oil-retaining quality—do not allow the oil to escape. Therefore only very little oil is wanted. A sprinkling or a fog of oil will suffice. The fog may be produced anyhow. It must only secure that the bearings are definitely under the influence of oil. The requirement

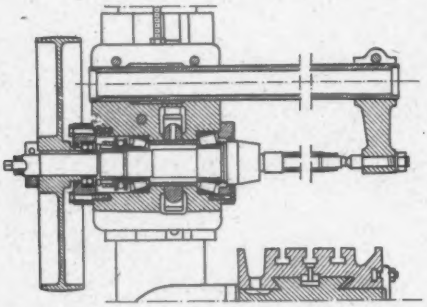

Fig. 33.—Timken roller bearing. Single rows of rollers in front and rear.

of self-alignment of the roller and ball bearings is partially given in the design itself. The edge loading which is so extremely dangerous for the plain bearing is avoided (comp. Fig. 6 and 7).

The pre-load also counteracts the danger of vibration. Further,

the adjustment of the clearance is very simple for taper roller bearings. Fig. 32 (see Fig. 7), shows a double roller (barrel) bearing for the front part of the main spindle. It can be adjusted by an intermediate washer and a journal with cylindrical rollers which is not adjustable for the rear end of the main spindle (heavy lathes of 28 h.p. John Lang). The numbers of revolution are not great

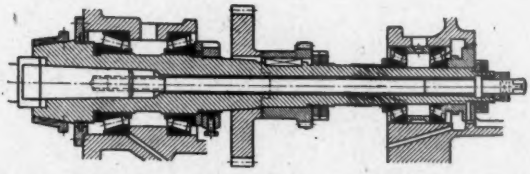

Fig. 34.—Main spindle of milling machine provided with Timken double bearings at front and rear.

in the present case. They vary between 6.5 —333 r.p.m. with a range of 1:50. This design ensures that the front bearing takes all stresses across and along and allows free extension of the warmed-up main spindle under heat.

The short length of the roller bearings is favourable to self-alignment. For the double bearings, therefore, single taper rollers in front and behind (Fig. 33) are superior to double-row bearings (Fig. 34). These journals have less clearance and consequently a better guidance and are just as rigid as a long plain bearing. The adjustability of the clearance for a taper or a barrel bearing may be

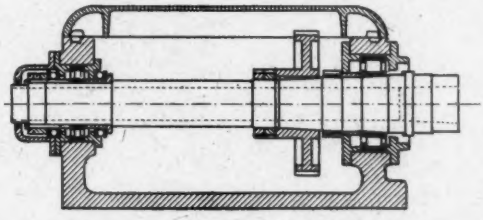

Fig. 35.—Cylindrical roller bearings, adjustable at front by internal taper race.

done by adjusting lengthwise one of the races, e.g. the right interior race (Fig. 34). The pre-load is adjusted by a distance ring which is inserted between the exterior races of the spherical front journal. (Fig. 32). The thickness of the washer is so chosen that the entire bearing works without clearance when by pre-loading the exterior races the bearing is running without clearance. The insertion

of the distance ring gives the advantage that the bearings can hardly be damaged by readjustment.

For heavy loads of the main bearings of lathes, drilling and milling machines cylindrical and taper roller bearings can be used. They must be chosen according to the speed and load they will have. The adjustability of cylindrical roller bearings cannot compete

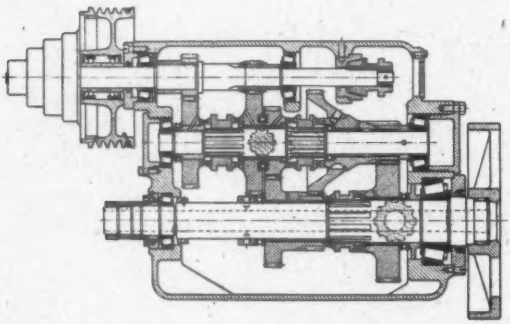

Fig. 36.—Headstock of lathe equipped with Timken bearings (Monarch).

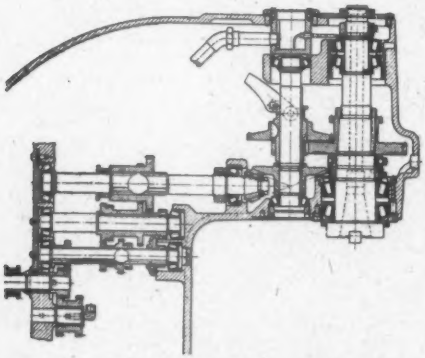

Fig. 37.—Gear box and main spindle of vertical milling machine (Cincinnati).

with the easy adjustment of the taper roller bearings. Up to now there is only one design known (Fig. 35). Here the solid inner race can be forced by a nut on a taper seat on the spindle so that the race is slightly expanded and allows adjustment of the oil clearance. Nowadays these bearings are successfully used in heavy lathes with multiple tools.

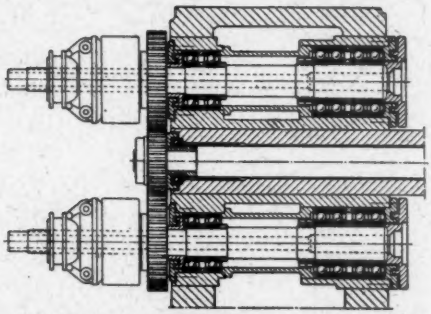

Fig. 38.—Multiple spindle turret lathe (Pittler).

Two ball thrust bearings at the rear are used to take the axial thrust. Fig. 36 shows a fast headstock which is well designed and exclusively uses Timken bearings. Fig. 37 shows the use of these roller bearings on a vertical milling machine.

The use of one row ball bearings for the main spindle is reserved for machines with high speeds and light loads. If the load is big there is the danger that either the balls are damaged or that they injure the races. Then the spindle would make a longitudinal

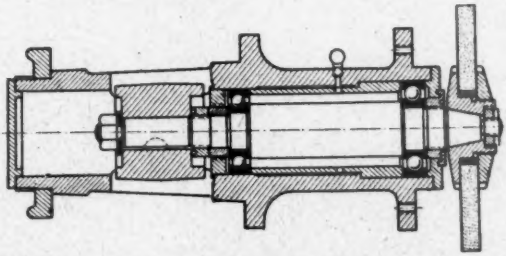

Fig. 39.—Spindle of a grinding machine locating ball bearings. Small axial force.

movement, with what is called the camming action. This is in no case allowed for the main spindle. If great forces must be taken the number of ball bearings must be multiplied.

Fig. 38 shows the arrangement of the main spindle of an automatic screw machine with multiple spindles and Fig. 39 that of a surface grinder. The latter design is remarkable since the thrust bearing also locates the lengthwise position of the spindle. The axial pressure, however, must not be too great (see Fig. 31).

With the small internal grinding machines which make up to 60,000 r.p.m. the cutting forces are very small. The internal grinder (Fig. 40) uses magneto-races under spring pressure. They

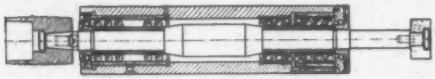

Fig. 40.—Spindle of an internal grinder with magneto- (one sided) ball bearings. (Tempo-Mueller).

have one-sided shoulders facing in opposite directions to take the axial forces in two directions. The extension of the spindle due to heating is possible without distortion because the fivefold rear ball race is of cylindrical exterior shape. For small vertical milling machines locating ball bearings likewise suffice. They are the same as used in the design of a small die-sinking machine running at from 2,000 to 12,000 r.p.m. (Fig. 41). If the existing construction

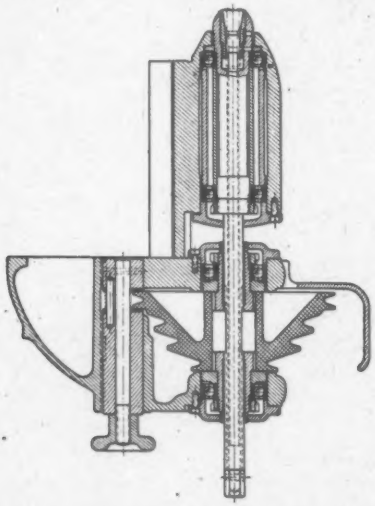

Fig. 41.—Small quick running milling machine for die-working. (Reed Prentice).

space is very limited needle roller bearings are used, which are nowadays of high quality. The use of the needle bearing is rather expensive because long hardened and ground guide bushings must

be used and because the main parts of the design (housing) must be used as races. The working surfaces must be hardened, ground and polished to keep the working diameters as small as possible. Needle bearings are seldom used below 500 r.p.m. The main spindle of the single automatic screw machine (Fig.41a) runs at 4,000 r.p.m. It does not allow recesses for the pulley because its wall is too thin. Therefore the lengthwise location of the needles of the rear bearing is made by side discs.

In 1934 a particular bearing with spherical self-adjusting blocks

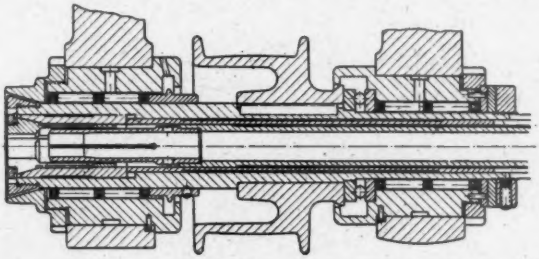

Fig. 41a.—Needle bearing requiring the smallest construction space for high speed automatic screw machine.

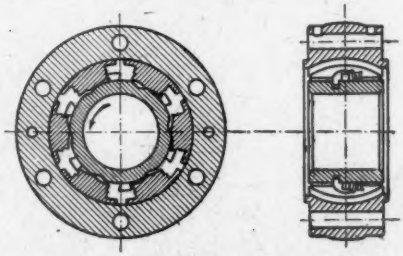

Fig. 42.—Section through "Nomy" bearing loaded radially with oscillating blocks (self-adjusting).

was designed by the Swedish Society of Nomy* (Fig. 42/44). Its design is of great interest. The special feature of it is the use of sliding and oscillating blocks with exterior spherical shape. These blocks are capable of universal adjustment, but they do not roll like the balls or rollers and on the other hand they are not as simple as the plain bearings. The designer took special care to guarantee the oilwedge for each block which is adjusted automatically with

* Bulletin "Nomy"-Ulvsunda, Stockholm, published 1935.

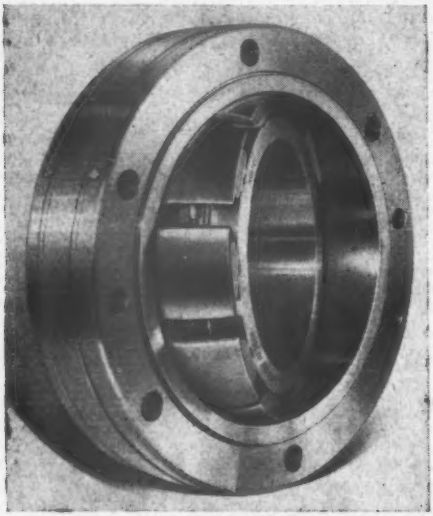

Fig. 43.—View of "Nomy" bearing.

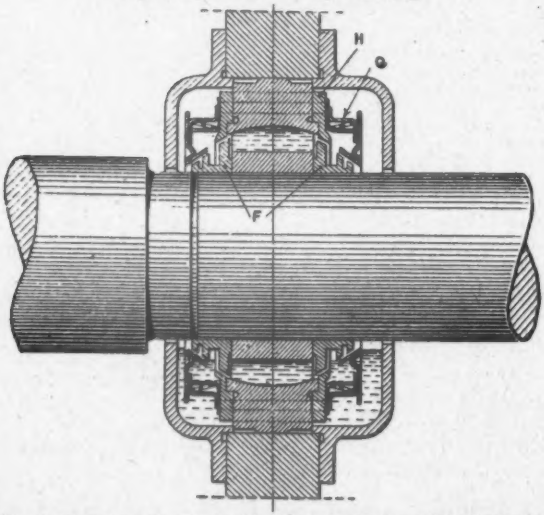

Fig. 44.—Section through "Nomy" bearing showing method of supplying oil and means employed to ensure tightness; working in both directions.

the direction of rotation and assures constant liquid friction. The arrangement of the oil bath (Fig. 44) to ensure circulation of the oil and the formation of a thin oil film is the basis for the life of the bearing.

A very good application of the wedge-shaped oil film on a grinding machine spindle bearing was made by the Filmatic bearing (Fig. 45) of the Cincinnati Grinding Corp. Rigidity is here essential in order to minimize the likelihood of chatter and feed lines. It also permits a more accurate duplication in plunge cut grinding, and provides a quick "spark-out" thus giving higher speed in the production of accurate dimensions. The Cincinnati Grinders Corp.—Cincinnati

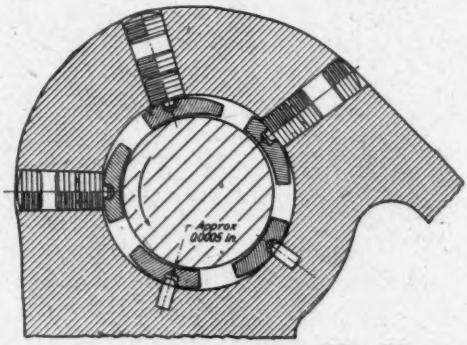

Fig. 45.—Section through "Filmatic" bearing of Cincinnati Grinder Corp.

formulates the following requirements* for a precision grinding machine spindle :—

1. An uninterrupted fluid film must be positively maintained between the spindle and bearing so as to prevent metallic contact and failure in service.

2. The axis of rotation when running idle must be maintained in a constant position—no fluttering or wavering can be tolerated.

3. Change in position of spindle axis with change in grinding forces must be as small as possible.

4. The bearing must be capable of supporting a load which varies in direction through a wide angle.

5. Frictional losses in the bearing should be substantially independent of applied load.

* The Wedge-Shaped Oil Film Does the Trick, by John Haydock—American Machinist, October 4, 1939.

6. Bearing must be as foolproof as possible, with minimum wear, and must not require adjustment for varying grinding conditions such as finishing and roughing.

Item 2 is essential for precision grinding machines.

In the " Filmatic " bearing the instability which is inherent in the single oil film structure is completely eliminated. In this design, three or more separate self-adjusting shoe members are used to produce independent converging oil films which develop high radial pressures, forcing the spindle into a central position.

In the arrangement shown, the spindle is locked in its central position by five " fluid vice jaws " which still permit perfect freedom of rotation with a coefficient of friction almost identical with that of anti-friction bearings. Because of the high preload, and also

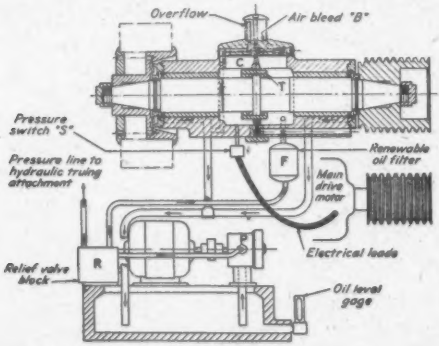

Fig. 46.—"Filmatic" bearing with pressure interlock.

because of the ability of the shoes to adjust their angle to accomodate the load, the movement of the spindle under a change in load is only a minute fraction of that which occurs in other types of bearings. Momentary fluctuations in the oil supply to the bearing shoes and the presence of entrained air were eventually completely eliminated in the " Filmatic " bearing by maintaining the oil supply in the bearing chamber at a pressure substantially higher than atmospheric and by providing an effective air bleeder system. This safety means comprises a pressure switch S, Fig. 46, which acts through a relay to prevent the starting of the spindle driving motor until the desired pressure has been built up within the bearing chamber. An independent motor driven oil pump P supplies oil through a filter F to the bearing, while a relief valve R maintains the chamber pressure at the desired value. The large central oil chamber C, which surrounds the thrust bearing T and

communicates with the chambers for both front and rear bearings, provides a relatively stationary body of oil from which the entrained air can be readily liberated and allowed to escape through the air bleed B. Because of the fact that, in this bearing, an uninterrupted oil film is positively maintained between the journal and bearing surfaces, its operation is virtually independent of the materials used for journal and bearing and the nature of the lubricating fluid. In the operation of a large number of machines equipped with "Filmatic" bearings, some of which have been in service over a period of five years, it has been found that all of the requirements listed in the earlier paragraphs have been fulfilled. These machines have ranged in power from 3 to 75 h.p., and in speed from 1,000 to 10,000 r.p.m.

The solving of the question of the best bearing for machine-tools under varying conditions by making systematic investigations with the existing good designs would be a great task for the Production Research Department.

Research Department: Production Engineering Abstracts

(Edited by the Director of Research)

NOTE.—*The addresses of the publications referred to in these Abstracts may be obtained on application to the Research Department, Loughborough College, Loughborough.*

COMBUSTION, FURNACE.

Premixing Practice, by R. F. Apter and Harry W. Smith. (*The Machinist, December 19, 1942, Vol. 86, No. 36, p. 947, 4 figs.*).

Gas-air flame treating permits the controlled selective heating of special sections of a part with regularly supplied fuels (manufactured gas, natural gas or propane) carburetted in long-familiar industrial equipment using only air to support combustion. Where city gas can be mixed with air and burned to achieve sufficiently localized and accelerated rates of heating, operating economies are considerable. The rate of transition between hardened and unhardened portions of test gears, two of which were quenched in oil and one in water. Proper selection of quenching time and temperature gives good final hardness contours. Compacted and radiant types of flame-hardening unit require gas and air mixing systems which incorporate integrally designed compressors in the mixture line.

COOLANT, LUBRICANT.

Coolants for Grinding Wheels. (*Machinery, December 3, 1942, Vol. 61, No. 1573, p. 635, 3 figs.*).

Recently, the results of researches on the influence of different coolants containing water, soda, emulsions and cutting oils have been published in Germany. (V.D.I. Zeitschrift 86-1942, p. 198). Decrease in radius of the grinding wheel in relation to the grinding time when using various cutting fluids. Abraded volume of workpiece in relation to the grinding time using different cutting fluids. Surface quality obtained with different grinding wheels and grinding fluids after 900 double strokes. In these investigations, the surface quality of the workpiece was in every case better with cutting oil than other fluids.

Correlation of Coefficient of Friction with Drilling Torque and Thrust for different types of Cutting Fluids, by A. O. Schmidt, W. W. Gilbert and O. W. Boston. (*Transactions of the A.S.M.E., U.S.A., October, 1942, Vol. 64, No. 7, p. 703, 15 figs.*).

Results of a series of tests made to determine the lubricating effects of a wide variety of cutting fluids on the forces involved in drilling. The investigation was conducted in the metal processing laboratories of the University of Michigan. Torque and thrust, from which the coefficient of friction was obtained, were measured on a special lubrication dynamometer and recorded graphically. Brief specifications are given for the cutting fluids used. The technique for carrying out lubrication tests and the results obtained are discussed, as well as those for the drilling tests. A comprehensive series of

graphs showing test results accompanies the paper, and clearly defined conclusions are drawn from the investigation.

EMPLOYEES, WORKMEN, APPRENTICES.

A Study of Employee Attitudes Towards Various Incentives, by Milton L. Blum and John J. Russ. (*Personnel, U.S.A., July, 1942, Vol. 19, No.1, p. 438*).

Wages are not the primary factor in job satisfaction, according to this attitude study of 286 workers. Such a finding corroborates the results of prior investigations in the field. Advancement and job security, the authors have found, rank well ahead of the pay envelope as factors in over-all morale. The article offers a number of other highly significant conclusions, and outlines a technique of attitude measurement that should have many possible uses for industry.

The Induction of New Factory Employees, by George E. Yeomans. (*Personnel, U.S.A., July, 1942, Vol. 19, No. 1, p. 390*).

Starting new employees off on the right foot may decisively affect their future job performance and morale. Unfortunately, many concerns compelled to expand their working forces as a result of the defence programme rely on hit-or-miss induction methods. The author appraises both formal and informal induction procedures, and offers a model programme that might well be adapted to these companies' needs.

Employment of the Coloured Worker, by Franklin O. Nichols. (*Personnel, U.S.A., July, 1942, Vol. 19, No. 1, p. 409*).

In this war for equality of all men, racial barriers in industry are steadily breaking down. More and more jobs are being declared open to the American nation's 13,000,000 negroes, and management is discovering that coloured men and women can work side by side harmoniously and efficiently with white employees. The article discusses the problems of race relations in industry and outlines the principles to be observed in the employment of coloured workers.

JIGS AND FIXTURES.

Jig and Fixture Details—IV, by John G. Jergens. (*The Machinist, December 5, 1942, Vol. 86, No. 34, p. 876, 14 figs.*).

Several forms of jacks or work supports which can be incorporated in jig and fixture design. Vice jaws intended to hold several parts simultaneously are shown as well as a quick-acting nut and an auxiliary leg for drill jigs that makes drilling at two different angles possible.

Densified Laminated Wood for Jigs and Tools, by A.E.L. Jervis. (*Machinery, December 17, 1942, Vol. 61, No. 1575, p. 673, 14 figs.*).

The field of application of synthetic-resin bonded, densified, laminated woods is wide, and in addition to aircraft propeller blades includes fan blades, silent gears, railway coachwork, models, mallets, and jigs and tools. Its strength makes it useful for certain ship applications, where it stands up well under the effects of gun fire. The material (Jabroc) is built up of veneers or laminations of certain woods, which are bonded together by glue or resin under great pressure, and between heated platens. Graph showing the tensile and compressive strengths of Jabroc for various densities. A typical deep drawing tool for press work. Flanging tools made from Jabroc. Tools for

the production of a wing component. A typical set of piercing and blanking tools. The properties of Jabroc compared with those of different metals. Physical characteristics of Jabroc compared with those of different woods. Jigs and tools. Its insulating properties combined with its other physical and mechanical properties, make Insuljabroc a valuable material in the field of electrical engineering. It is very resistant to acids and oils.

MACHINING, MACHINE TOOLS.

Heat Treatment and Machinability of S82 Gears. (*Mechanical World, December 18, 1942, Vol. CXII, No. 2920, p. 579, 5 figs.*).

The material covered by the Air Ministry Specification S82 is a case-hardening alloy steel which is used where maximum strength, high surface hardness and shock resistant characteristics are desired, but this steel as a direct result of its high alloy content is one of the most difficult steels in which to obtain reasonable machineability at the various operations. Composition, and physical properties in the heat treated condition. Distortion. Single quench treatment. Quenching on a falling heat. Microstructure and machineability. Three different heat-treatments were tested. The best results re : shortest treating and best machineability, gave lay-out No. 3 with the following operations : 1. Part forged ; 2. Austemper treatment—840°C. transferred to furnace at 650°C. and cooled in air. 3. Rough machine. 4. Carburised 890°C. and cooled in boxes. 5. Refined 840°C. quenched in oil. 6. Annealed 650°C. for 2 hours cooled in air. 7. Machining completed except grinding. 8. Hardened 760°C. quenched in oil. 9. Tempered 140°C. for 1 hour cooled in air. 10. Grind.

The Working of High-Nickel Alloys. (*The Machinist, December 12, 1942, Vol. 86, No. 35, p. 885, 7 figs*).

Materials available. Characteristics of wrought and cast nickel-base alloys. Hot and cold working nickel-base alloys : hot forming. Cold forming. Shearing. Punching. Deep drawing. Spinning. Heat-treating procedures. Hastelloy alloys. Pickling solutions and procedures. Machining practice for high-nickel alloys. Feeds, cuts and speeds for machining nickel and monel. Turning and boring. Cutting fluids for nickel and high-nickel alloys. Screw machine work. Planing and shaping. Speeds and feeds for machining hastelloy alloys A, B and C with Stellite cutting tools. Milling operations. Drilling operations. Feeds and speeds for automatic screw machining of " R " monel and " KR " monel (unhardened). Reaming operations. Tapping operations. Lathe threading. Die threading. Filing operations. Cutting-off operations. Precision grinding. Joining practices for high-nickel alloys. Riveted joints. Soft soldering. Silver brazing. Oxyacetylene welding. Electric arc welding. Atomic hydrogen welding. Resistance welding. Welding fixtures.

Thread Grinding with Electrical Control, by L. M. Davis. (*Machinery, December 17, 1942. Vol. 61, No. 1575, p. 681, 3 figs.*).

The Jones & Lamson automatic thread grinder in which the wheelhead, truing device, workhead, cam drum, and coolant pump are designed as separately-driven units. Typical thread-grinding cycle. Adaptability. Electrical control used for fully automatic operation.

Working Conditions and Performances of Fine Finishing Operations, by G. Schlesinger. (*Machinery Lloyd, December 12, 1942, Vol. XIV, No. 25, p. 37, 8 figs.*).

Finishing operations are fine turning, fine boring, fine grinding, lapping, or honing. However, the modern trend is to refine these fairly fine finished

surfaces of a degree from 4 to 16 micro-inches (average) roughness to a much finer quality of 0.5 to 2 micro-inches. Only the finest finishing operations, such as mechanical lapping, micro-honing and super-finishing developed in the last five to six years, produce surfaces between 0.5 and 2 micro-inches (average) at sufficient uniformity and with bearing areas between 80% to 90%. Microphotographs and pen records of ground diamond, turned, lapped, honed, superfinished surfaces. Paths of abrasive grains for lapping, super-finishing and honing. Internal lapping machine head. Cam contour super-finisher. Examples of honing and microfinish by honing. Working conditions and performance of the finest finishing operations.

Gear Shaping and Shaper Cutters, by Charles R. Staub. (*Machinery, December 10, 1942, Vol. 61, No. 1574, p. 651, 8 figs.*).

The manufacture of accurate and, therefore, quiet gears by the shaping or involute generating process, presents a number of problems. Each requires analysis and solution, if gears which can be considered satisfactory for the many precise applications demanded today are to be produced. It is important to note, that unless the equipment available for checking the accuracy of gears is adequate, it is often difficult and sometimes impossible to locate the cause of any inaccuracy. Generating. If both gears have the same basic tooth form, it is obvious that they will mate properly; they may be hobbed or shaped. Modified tooth forms. Root fillets. Possible machine errors. Characteristics of gear shaping. Limits for shaper cutters of (1) 5 D.P. and coarser and 4 to 8 inches pitch diameter. Limits for shaper cutters of (2) 4 D.P. and finer and up to 5 inch pitch diameter. Hints on cutter sharpening. Checking gear shaper cutters.

CHIPLESS MACHINING.

Drop-stamping. (*Aircraft Production, January 1943, Vol, V,, No 51, p. 6, 14 figs.*).

Using the Cecostamp to speed-up production of compound-curvature sheet metal parts.

MANUFACTURING METHODS.

Performance of Mechanically Reconditioned and Chemically Sharpened Files, by H. Schallbroch and W. Beiling. [*Werkstatt and Betrieb, (Germany), Vol. 75, No. 8, August 1942, p. 175*].

The mechanical reconditioning virtually consists of grinding off the teeth and fitting new teeth to the resulting steel blank. Since the subsequent hardening can never be as favourable as that carried out by the manufacturer of the original file (due to lack of knowledge of material specifications) such reconditioned files seldom approach the performance of the original article. Moreover the grinding leads to a serious loss in strength due to loss of material and this cannot be applied to small thin files. As an alternative to this method of reconditioning, attempts have been made to utilise sand blasting, wire brushes or chemical treatment. The authors are primarily concerned with the latter method and carried out extensive experiments on files "resharpened" by the Zoppi and Ullmann methods respectively.

Zoppi Method (German Patent application Z.23562 VI/48d).

The files are first degreased in an alkaline bath and then freed from rust by immersion in a 50% HCC bath for 12 hours at room temperature. A mechanical treatment with rotating brushes is interposed at various stages of the treatment. The sharpening process proper is carried out in a 16% HNO_3 bath and lasts 10 to 20 minutes. The files are then washed and provided with a protection against corrosion.

Ullman Process (German Patent No. 709248).

After degreasing, derusting and brushing as in the Zoppi process, the files are immersed in a bath of the following composition by weight :

Copper sulphate	11.2
Concentrated H_2SO_4 (free from arsenic) ...	27.5
Nitric acid	36.3
Potassium dicromate	9.0
Water	500.0

The time of immersion is about 8—10 minutes. The file is then rinsed and any remaining acid neutralised.

By choosing the angle of immersion correctly, it is claimed that the clearance flank of the tooth is covered with a deposit of cover, the chemical etching effect then being concentrated on the steeper cutting edge.

Files reconditioned by both methods were tested in a special test rig, in which the file is reciprocated under load on a ball bearing steel. Records were kept of the gradual blunting of the file teeth (actual tooth profile photographed at grazing incidence). The wear of the steel specimen and the nature of the filings produced. It appears from these experiments that both the chemical methods described produce a marked improvement in the performance of the previously blunted file and that moreover the treatment can be repeated several times.

(*Communicated by D.S.R. Ministry of Aircraft Production.*)

Avro Lancaster, by Wilfred E. Goff. (*January, 1943, Vol. V, No. 51 p. 10, 31 figs.*).

Part I, Britain's latest four-engined bomber in production : building the centre section and the outer wings.

MATERIALS, MATERIAL TESTING.

Rapid Identification of Non-Ferrous Scrap. (*Metal Industry, November 6, 1942, Vol. 61, No, 19, p. 294*).

Material	*Surface Appearance*	*Magnet Test*	*Lathe Chip Test*	*Blowpipe Test*
Nickel	Dark grey; smooth; sometimes green (oxide)	Magnetic	Cuts easily ; smooth edges ; can be continuous	Melts slower than steel ; less slag than Monel; quiet puddle
Monel	Dark grey; smooth	Slightly magnetic at room temperature	Cuts easily ; smooth edges ; can be continuous	Melts slower than steel: considerable quiet slag ; quiet puddle
"Nickel silver"	Grey to yellow or yellow to green	Non-magnetic	Smooth, long, often continuous chips	Moderate melting speed ; fumes
Brass	Yellow to green or brown	Non-magnetic	Smooth, long chips ; more brittle than copper	Moderate melting speed ; gives off fumes ; puddle like water

Material	*Surface Appearance*	*Magnet Test*	*Lathe Chip Test*	*Blowpipe Test*
Tin bronze	Red to brown	Non-magnetic	Smooth, long chips; more brittle than copper	Fast melting, some fumes; puddle like water
Aluminium Bronze	Yellow brown	Non-magnetic		
Copper	Smooth red-brown to green (oxides)	Non-magnetic	Smooth, long easily cut chips	Slow melting; very little slag; puddle bubbles
Aluminium	Light grey to white; dull or brilliant	Non-magnetic	Smooth chips; saw edges where cut; chips can be continuous	Very fast melting; quiet black scum forms, quiet puddle
Magnesium Alloy	White; surface coating may be yellow-brown	Non-magnetic	Short, easily cut chips	
Lead	Smooth, velvety white to grey	Non-magnetic	Cut by knife; any shape chip	Melts very fast; quiet slag, dull grey coating; quiet puddle
Lead-Silver Solder	Smooth; dark grey; sometimes discoloured	Non-magnetic	Harder than lead; any shape chip	Slower melting than Pb or Pb-Sn
Lead-Silver Solder	Smooth; dark grey; sometimes discoloured	Non-magnetic	Harder than lead; any shape chip	Slower melting than Pb or Pb-Sn
Lead-Tin Solder	Smooth; white to grey; may be frosty	Non-magnetic	Harder than lead; any shape chip	Faster melting than Pb-Ag; about same as lead

CHEMICAL OR SPOT TESTS

Material	1. *Nitric Acid*	2. *"Iron Nail" Test*	3. *Ammonia Test*	*Others*
Nickel	Reacts slowly; pale green solution	Negative	Blue	No. 4—Intense red colour
Monel Metal	Reacts; greenish blue solution	Copper plates out	Dark blue	No. 4—Intense red colour
"Nickel Silver"	Reacts; bluish-green solution	Copper plates out	Dark blue	No. 4—Red colour varies in intensity with nickel content

Material	1. *Nitric Acid*	2. *"Iron Nail" Test*	3. *Ammonia Test*	*Others*
Brass	Reacts vigorously green solution	Copper plates out	Dark blue	No.4—No red colour in nickel-free alloys
Tin Bronze	Reacts vigorously; blue-green solution	Copper plates out	Dark blue	
Aluminium Bronze	Reacts vigorously blue-green solution	Copper plates out	Whit ppt; blue solution	
Copper	Reacts vigorously; blue-green solution	Copper plates out	Dark blue	
Aluminium	Soluble		White precipitate	
Magnesium Alloy	Soluble		Colourless	
Lead	Soluble		Colourless	No. 5—No precipitate
Lead-Silver Solder	Soluble		Colourless	No. 5—No precipitate in absence of tin
Lead-Tin Solder	Soluble		Colourless	No. 5—Black deposit with white ppt

Spot Test Procedures

Test No. 1—Nitric Acid Test.

Place 1 or 2 drops of concentrated nitric acid on the clean metal surface. Observe any reaction for 1—2 minutes. Then dilute with 3—4 drops of water, and observe reaction. If solution turns green or blue use it for the " iron nail " test.

Test No. 2—Iron Nail Test.

Rub a clean iron nail in the coloured acid solution, in contact with the specimen. If the alloy contains copper, copper will be deposited on the nail or the metal surface.

Test No. 3—Ammonia Test.

Dissolve a bit of the metal in nitric acid, or attack the surface with a few drops of acid. Dilute somewhat, carefully add ammonium hydroxide to the solution until the latter is strongly alkaline. If copper or nickel is present, a pale blue precipitate will form, which on further ammonium hydroxide addition becomes a dark blue solution.

Test No. 4—Paper Test for Nickel. (*Williams, Ind. & Eng. Chem., January 1942*).

One drop of acid mixture (10 ml. H_2SO_4, 10 ml. HNO_3, 10ml. H_3PO_4, 10 g. citric acid, 25 ml. water) is placed on the metal for 15—30 seconds, then absorbed in a paper test strip (filter paper dipped in a solution of 10 g. citric acid, 25 ml. H_2O, 10 ml. of 1% dimenthyglyoxime in isopropanel and dried). When KOH is dropped on the paper, a red colour will form if nickel is present. This test is free of colour interference from iron or other elements.

Test No. 5—Silver Nitrate Test for Tin.

Treat the clean metal surface with a few drops of 2½% silver nitrate solution. If tin is present, a black deposit with a white precipitate will form.

(*Communicated by D.S.R. Ministry of Aircraft Production.*)

A Comparison of the Mechanical Properties of American and D.T.D. Type Test Bars in Various Magnesium Alloy, by J. L. Walker. (*Magnesium Rev. and Abstracts, September, 1942, Vol. 3, No. 1, p. 3*).

The mechanical properties quoted for Mg alloys are, in this country, obtained by tests on the D.T.D. type test bar. American test data are usually obtained from test bars of a different type. The work described was undertaken to enable quantitative comparison to be made.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Frictional Properties of Bearing Metals, by J. L. Heaton and others. (*Nature, October 31, 1942, Vol. 150, No. 3809, p. 520*).

Tests on the frictional properties of a thin film of a soft metal such as Pb, Cd or Sn wiped on to Cu by hand show that the coefficient of friction at low speeds is less than that of either the soft metal or the hard base. Authors conclude that the thin film acts as a lubricant and suggest that in a heterogeneous bearing metal such as Pb bronze the soft phase wipes out over the hard phase during sliding, acting as lubricant under conditions of ordinary lubricant breakdown.

(*Communicated by the British Non-Ferrous Metals Research Association*).

MEASURING METHODS, APPARATUS.

Limits between Holes. (*Machinery, December 24, 1942, Vol. 61, No. 1576, p. 705, 3 figs.*).

A problem which confronts the jig designer is that of keeping the limits of the dimensions between bush-hole centres as large as possible, and, at the same time, avoid interference when the drilled components are assembled. Three examples are discussed : (1) that of two holes ; (2) two holes of a four-hole arrangement ; (3) six holes arranged hexagonally.

PLASTIC MATERIAL.

Bonding of Plastic to Metal Sheet (Anchoring by means of burred holes in the latter) (Plastel). (*N. A. de Bruyne, British Plastics, Vol 14, No. 162, November, 1942, pp. 306, 316 and 349*).

By bonding sheet metal to plastics, both the flexural stiffness and dimensional stability of the panel are increased. It is easily shown that if the bonding is perfect, much greater stiffness can be obtained than is possible for the same weight of steel alone or plastic alone. By choosing the optimum

ratio between thickness of filler and thickness of cover plates, the composite structure will be 2½ times as stiff as a dural panel and 15 times as stiff as a steel panel of the same weight. Similarly, the stiffness of plywood can be increased 10% by sheeting it with dural. Approximately perfect bonding can be obtained with certain kinds of cement. As an alternative, the metal sheet can be attached to the plastic direct, by providing the former with burred holes in which the plastic (thermosetting or thermoplastic) is anchored. The product obtained by this simple method is known as Plastel and although the adhesion is not perfect, the resultant structure is still about 20% stiffer than a dural panel of equal weight. Quite apart from increased flexural stiffness, the metal bonding ensures greater dimensional stability to the plastic under changes of humidity and temperature. As is well known, transparent panels of cellulose acetate are apt to crack round the bolt holes where they are secured. This can be completely cured by bonding the edges with metal. In the same way, the danger of starring or splintering when drilling holes in acryl resin sheets can be avoided by "plastelising."

Another interesting application of metal bonded plastics is the construction of screening panels for wireless installations. By removing the surface metal by means of a simple trepanning tool, through connections can be made without the use of separate insulating bushes. The simple method of bonding is also applicable to the surface of airscrew blades made of resin bonded wood.

(*Communicated by D.S.R., Ministry of Aircraft Production*).

The Strength of Gear Wheels Made of Laminated Plastics. (*Digest, Z.V.D.I. Germany, Vol. 86, No. 41-42, October 17, 1942, p. 638*).

The report covers investigations on the strength of individual teeth of gear wheels manufactured either from a plastic bonded or compressed wood. All the wheels examined had a pitch circle of 195 mm. thickness 50 mm., and were provided with a central hole of 75 mm. The tooth modulus varied from 3 to 7.

The following average results were obtained :—

	Bending Strength	Bending Fatigue (10^7 reversals)	Impact Strength
Plastic Work Fabric filler (coarse)	1360 Kg/cm²	400 Kg/cm²	17-31 Kg cm/cm²
Plastic Work Fabric filler (fine)	1588 Kg/cm²		
Bonded Wood	1785 Kg/cm²	800 Kg/cm²	55-160Kg cm/cm²

It appears that the bending strength is independent of the tooth modulus. The value given for the bending fatigues apply for tooth modulus of 5 and 7. A smaller modulus (3) give apparently lower value. In the case of impact strength, there is a marked effect of the tooth modulus, the value increasing with the latter. The figures given for the bonded wood are for a tooth modulus of 7 and the large range of experimental value will be noted.

(*Communicated by D.S.R., Ministry of Aircraft Production*).

RETAILING.

Compacting Steel Swarf by Auto-Combustion (Scrap Disposal). (*Stahl and Eisen, Germany, Vol. 62, No. 44, October 29, 1942, p. 921*).

Steel wool or swarf is very awkward material to handle, If spread relatively thinly in the open, considerable space is required and if stacked to any height subsequent handling is made very difficult by interlocking. Transport is very uneconomical since a 20 ton truck will not normally hold more than about 5 tons of swarf.

Remelting at the steel works is also difficult, the possible rate of addition to the normal charge being strictly limited (stoppage of flue and air filters, especially if swarf is oily).

The author describes a simple method of compacting the swarf by purely thermal means before dispatch for disposal.

For this purpose, the swarf is introduced into a simple type of vertical furnace (illustrated) and ignited by means of a small wood or coke fire. Once combustion has started, no fresh fuel need be added, the heat generated by the combustion of part of the bottom layer of swarf being sufficient to either melt the swarf or break it up into very small lengths. Less than 10% of the charge leaving the furnace is in the form of oxide, the remainder being metallic iron. In practice, the compacting furnace is set up in close proximity to the swarf mound and charged with a crane as required. The compacted product leaves the furnace at the bottom and is directed into a conveyor, the belt of which is continuously cooled with loamy water. The standard furnace will handle about 2 tons of swarf an hour and the resultant product presents no difficulty when added to the normal charge of the blast, Siemens Martin or electric furnaces.

A large number of such furnaces are now in use and by this means storage room is reduced, transport of swarf rendered economical and scrap recovery facilitated.

(*Communicated by D.S.R., Ministry of Aircraft Production*).

SHOP MANAGEMENT.

The Relation of Long Hours of Work to Reduce Output, by H. M. Vernon. (*Industrial Welfare and Personnel Management, November-December, 1942. Vol. XXIV, No. 285, p. 174*).

Long hours of work do not inevitably yield a smaller output than that obtained with shorter hours. However, in the article, this result does frequently happen, for the reasons stated. Absenteeism. Sunday labour. Health. An investigation made at 140 establishments in the U.S.A. covering 2,000,000 employees seemed to indicate that a 40 hour week was the optimum for women, and a 48 hour week for men.

SMALL TOOLS.

High-Speed Milling with Carbides, by Captain E. G. Moffat. (*The Machinist, December 19, 1942, Vol. 86, No. 36, p. 933, 6 figs.*).

Watervliet Arsenal has developed a method of milling steel with sintered carbides. The new method involves a radically different cutter design, a new type of sintered carbide and an exceptionally light feed per tooth per cutter revolution but a high rate of table feed because of extremely high cutting speed. Carbide-tipped blades for double negative rake milling cutters should be secured in place with a positive locking device, or brazed in position in the cutter body, to eliminate the danger of the blades loosening. In the new cutter, both the rake and the helix angles are negative. This design of cutter tooth makes possible the successful milling of steel with sintered carbide A negative rake shears the chip from the work and avoids the built-up edge. High-speed carbide milling of steel is done dry. Honing improves tool life. A comparison of the strength of cutter blades ground and set for positive and negative rakes shows one of the advantages of the latter.

Tangential Chasers. (*Machine-Tool Review, September-December, 1942, Vol. 30, No. 182, p. 81, 11 figs.*).

Cutting action. Throat, lead, rake and helix angles. Grinding instructions Cutting speed. Cutting lubricant. Angles involved when grinding tangential chasers. Universal grinding fixture for tangential chasers. Shape of grinding wheel for grinding rake. Method of grinding coarse pitch chaser for use with a lead screw.

Carbide Dies for Drawing and Sinking Metal Tubing, by E. Glen, (*Iron Age, August 27, 1942, Vol. 150, No. 9, p. 64*).

Materials and design for carbide dies and mandrels for drawing tubes of Cu, Cu-Ni, etc.
(*Communicated by the British Non-Ferrous Metals Research Association*).

"Hardsteel"—A New Material to Speed Production for War, by L. G. Black. (*Machinery-Lloyd, December 26, 1942, Vol. XIV, No. 26, p. 43, 4 figs.*).

"Hardsteel" is made up into drills, reamers and tool bits which drill, countersink, counterbore, ream and machine extremely hard materials such as steels hardened by any process—carburised, nitrided, cyanided, oil or water quenched—armour plate, hard plastics, amorphous carbon and the abrasive copper, brass, bronze and aluminium alloys. Speeds are higher than for drilling mild steel with high speed steel drills. They are :

Drill size, in.	Drill speed, RPM.
$\frac{1}{8}$	2,000 to 2,500
$\frac{1}{8}$ to $\frac{3}{16}$	1,600
$\frac{3}{16}$ to $\frac{1}{4}$	1,400
$\frac{1}{4}$ to $\frac{3}{8}$	1,200
$\frac{3}{8}$ to $\frac{1}{2}$	900
$\frac{1}{2}$ to $\frac{5}{8}$	800
$\frac{5}{8}$ to $\frac{3}{4}$	700
$\frac{3}{4}$ to $\frac{7}{8}$	600
$\frac{7}{8}$ to 1	500

"Hardsteel" tool bits, increase speed and feed to approximately twice that used with high speed bits.

STANDARDISATION.

Recommended Tap Drill Sizes—III and IV. (*The Machinist, Reference Book Sheet, December 5, 1942, Vol. 86, No. 34*).

Sizes of tap drills, American National coarse-thread series.

Recommended Tap Drill Sizes—IV. (*The Machinist, Reference Book Sheet, December 26, 1942, Vol. 86, No. 37*).

Sizes of tap drills, American National fine-thread series.

Allowances for Shaft Fits, by R. P. Valtier. (*The Machinist, Reference Book Sheet, December 26, 1942, Vol. 86, No. 37*).

Development of Standards for Army Ordnance Finishes, by Mary R. Norton. (*Mechanical Engineering, U.S.A., October, 1942, Vol. 64, No. 10, p. 703, 13 figs.*

"Drafting Room Regulations of the Ordnance Department, U.S. Army," revised April 2nd, 1941. A national standard would be particularly desirable for Ordnance work, which, in time of emergency, may have to be done in any

shop in the country. Proposed American standard : specification for surface roughness. Working plan for introducing standardization into an individual organization involves the following steps : (1) Survey of existing practice. (2) Study of results of survey. (3) Formulation of proposals for standards. Ordnance finishes of artillery carriage and cannon ; fire control ; small arms ; tank and combat vehicles for bearings ; artillery ammunition. The proposal for a British standard. Possible limiting sizes of irregularities revealed by different methods of evaluating surface finish. Summary of surface roughness measurements.

SURFACE TREATMENT.

Metallizing as a Method of Water Works Maintenance, by C. E. Palmer. (*J. Amer. Water Works Assoc., September 1942,, Vol. 34, No. 9, p. 1374*).

An account of a number of examples of metal spraying.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Surface Finish of Journals, by R. W. Dayton, H. R. Nelson, and L. H. Milligan. (*Mechanical Engineering, U.S.A., October, 1942,, Vol. 64, No. 10, p. 718, 7 figs.*).

As affecting friction, wearing-in, and seizure of bearings. Data are reported for steel surfaces finished by grinding, sandpapering, loose-abrasive lapping, and "hyprolapping." The specimens were made of S.A.E. 6150 spindle steel hardened to 42 Rockwell C. Every effort was made, however, to control the conditions of preparation so that reproducible surfaces could be obtained. Table : Preparation of various surface finishes. Characteristic friction-load curves obtained in seizure tests of rough and smooth shafts. Preliminary tests with four bearing materials. Tests of steel specimens with various finishes against copper-lead bearings. Average results for steel specimens arranged according to excellence as measured by initial seizure load. Effect of surface roughness. The wearing-in of surface finishes. Initial and final seizure loads, plotted against product of profilometer readings that were taken in axial and circumferential directions on test shafts. Summary : It was found that there was rather good correlation between the seizure results and the product of profilometer readings taken in the axial and circumferential directions. Those surfaces having higher roughness product readings had greater seizure tendency.

TECHNICAL EDUCATION.

Training for War Production : A Case Study. (*Personnel, U.S.A., July, 1942, Vol. 19, No. 1, p. 418*).

Training as a policy and a solution. Forecast of manpower requirements. Employment procedure. Vocational school course for machine operators. Company pre-employment course for machine operators. On-the-job training. Training for foundry workers. Training engine testers and assemblers. Upgrading. Apprenticeship and supervisory training.

WELDING, BRAZING, SOLDERING.

Welding. (*U.S. War Dept. Tech. Manual, T.M. 1-430, April 24, 1942, p. 180*).

Oxyacetylene welding equipment ; welding fundamentals ; arc welding ; resistance welding ; welding steel and ferrous castings ; welding Al and alloys, Mg alloys, Ni alloys (Inconel, Monel) ; Cu and alloys ; brazing and silver

soldering ; hard facing with Stellite or tungsten carbide ; aircraft construction and repair by welding.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Spot-Welding Light Alloys. (*Aircraft Production, January, 1943, Vol. V, No. 51, p. 3, 4 figs.*).

The introduction of new and improved stored energy spot and roll-welding machines has made it possible to considerably increase the number of parts that may now be spot-welded. To weld alloys of aluminium and magnesium, welding currents up to 35,000 amps are necessary. The Sciaky automatic cycle, showing in graphical form the variable electrode pressure and welding current. Four main basic requirements are essential for the satisfactory spot-welding of sheet aluminium alloys. Extremely quick generation of fusing heat at the weld spot, rapid cooling and solidification of fused metal under high pressure, accurate maintenance at constant values of the electric force and rate of flow, and the minimum adherence of surface metal to the electrode tips. Preparation of work. Chromic-sulphuric acid pickling. Electrodes. Securing the work. A.C. and D.C. types.

Silver Brazing Alloys and Solders, by Herbert Chase. (*The Machinist, December 5, 1942, Vol. 86, No. 34, p. 216E*).

Wider use of silver-bearing solders and brazing alloys is likely to result from restrictions on tin. Advantages : low melting point ; good malleability and ductility, ability to make joints of great strength, good corrosion resistance and high electrical and thermal conductivity. Of the brazing alloys, often called " hard silver solders," those that melt at 1,175 to 1,200 deg. F. and flow freely at or below 1,300 deg. F. are easiest to work with and possess most of the advantages of the silver brazing alloy series. Since joints have maximum strength when the solder thickness in the joints is 0.001 in. to 0.003 in. little brazing alloy is needed. Table containing : Composition, by weight, per cent, melting point (solidus temp) ; flow point (liquidus temp.) ; colour. Silver solders may be characterized as " soft " but their melting range is well above that of ordinary " soft " tin-lead solders.

WELFARE, SAFETY, ACCIDENTS.

Planning Industrial Recreation, by G. H. Duggins and Floyd R. Eastwood. (*Personnel, U.S.A., July, 1942, Vol. 19, No. 1, p. 398*).

Longer hours and the quickened tempo of war production have made employee recreational activities more important than ever before. The effects of increased tension on employee health and morale may be counteracted by an intelligently planned programme of industrial recreation. The authors of this article have surveyed successful recreation programmes in a number of companies, and from their study have drawn up a model plan for such a programme. They explain how to organise a recreation association, how activities should be planned, and how a programme may be financed for as little as 14 cents per employee per week.

At the Foot of Production, by A. J. R. Bride. (*Industrial Welfare and Personnel Management, November-December, 1942, Vol. XXIV, No. 285, p. 176*).

Disabilities directly due to occupation. Indirectly due to occupation. Not necessarily due to occupation. Footwear. Cleanliness. What is being done? What could be done.

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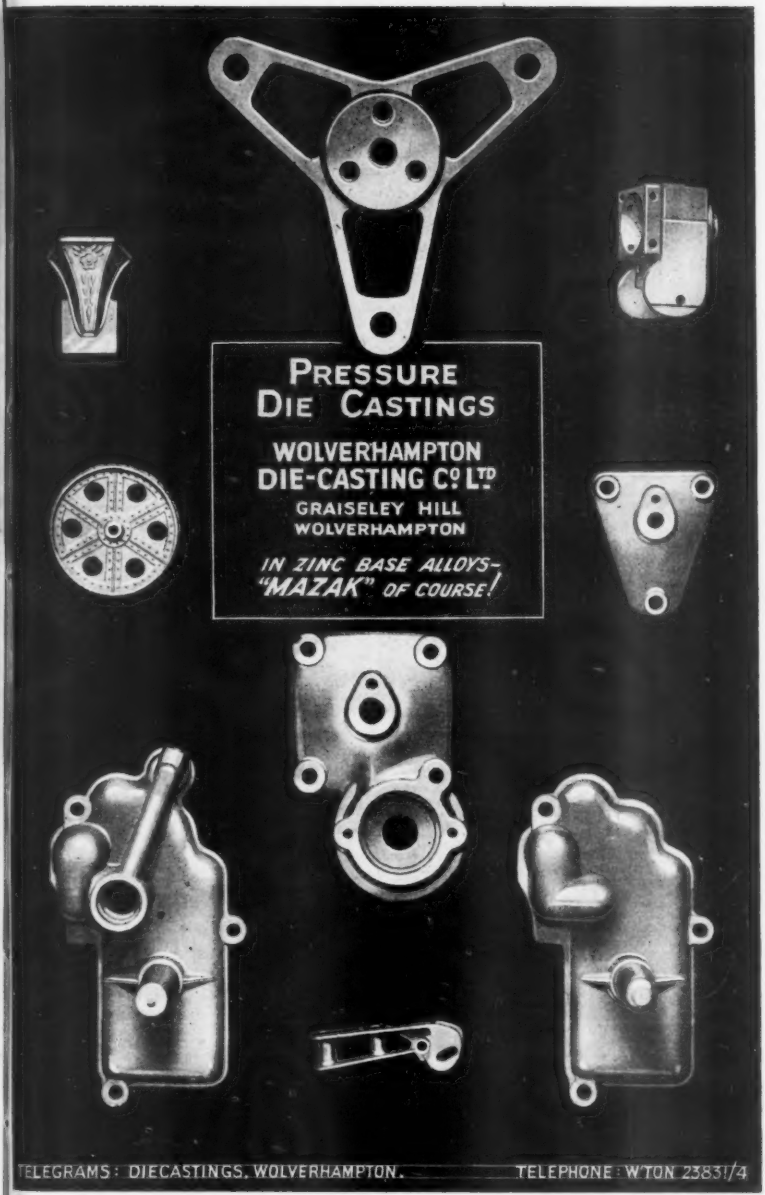
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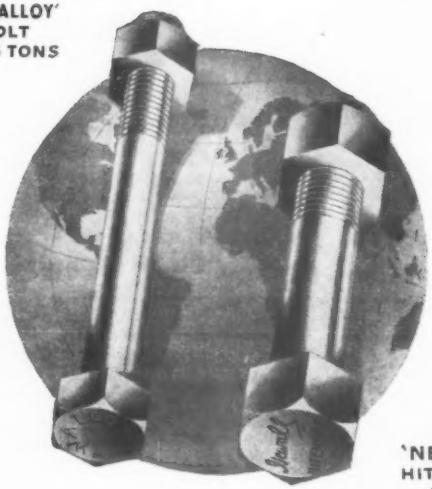

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